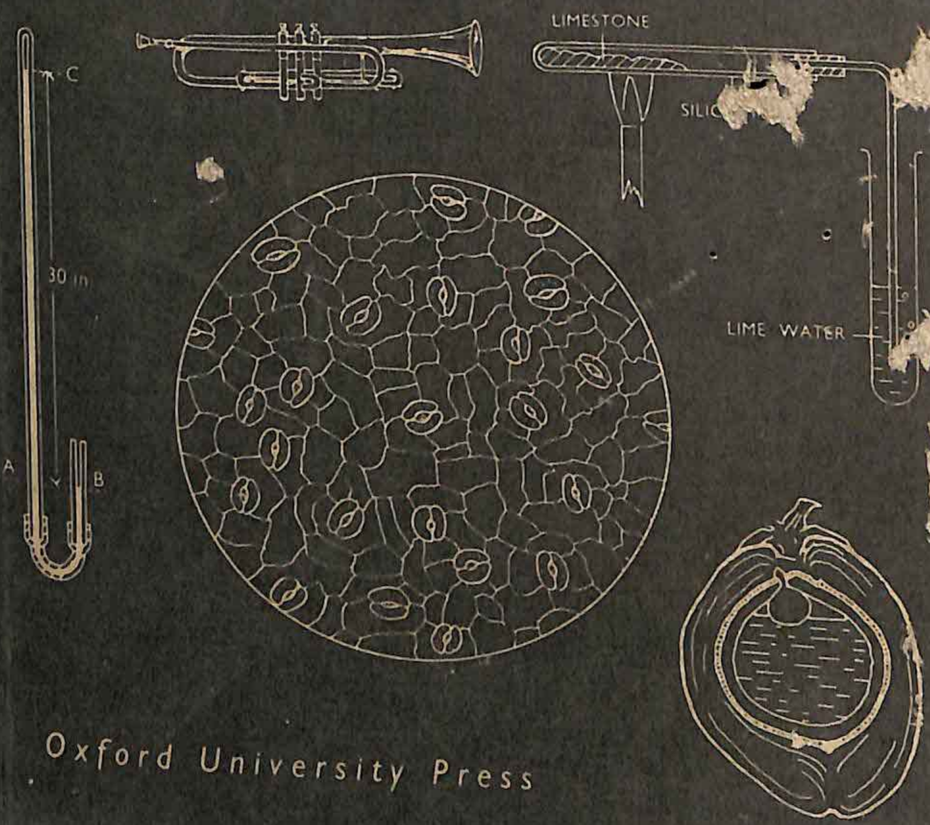
# GENERAL SCIENCE
# FOR TROPICAL SCHOOLS
## Book Two
by F. DANIEL

Govt. of West Bengal



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Deputy Director of Public Instruction,
(Planning), West Bengal.

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# FOR TROPICAL SCHOOLS

## BOOK II

STATE INSTITUTE OF EDUCATION

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## FOR TROPICAL SCHOOLS

BY

F. DANIEL

BOOK II

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## GENERAL SCIENCE FOR TROPICAL SCHOOLS

*By* F. DANIEL

A four-year course for secondary schools, especially written for use in tropical and sub-tropical areas. It consists of four books (I–IV), with an optional volume on Health Science (IIIA). There is also a Teacher's Handbook, which gives practical suggestions for the design and equipment of laboratories, lists of apparatus necessary for this General Science Course, examination questions and useful hints arising out of the author's experience in conducting the course.

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APPENDICES: A. General Instructions for Science Classes. B. Scientific Apparatus and Diagrams. C. Weighing. D. Accuracy.

BOOK II: LIMESTONE, SALT, AND THEIR DERIVATIVES: carbon dioxide—common salt—hydrogen chloride—chlorine—acids, bases, and salts.

PROPERTIES OF MATTER: surface tension—air pressure—liquid pressure.

PLANT LIFE: leaves—photo-synthesis—respiration—transpiration—importance of water. Flowers; pollination and fertilization. Fruits and seeds.

THE SOIL: formation—constituents—mineral matter—organic matter—air and water in the soil—plant food—micro-organisms—manures—composting—crop rotation.

SOUND: vibration—waves—resonance—musical instruments.

BOOK III: HEAT: temperature and thermometers—expansion—movement of heat—ice, water, and steam—humidity—quantity of heat—change of state—latent heat—heat and work—heat engines—heat and living things.

ANIMAL LIFE: the highest animals—food and digestion—transport—respiration—excretion—cells and tissues.

OTHER LIVING THINGS: the simplest living things—evolution—non-flowering plants—invertebrates—lower vertebrates.

LIGHT: nature and laws—reflection—refraction—lenses—optical instruments—colour—light and living things.

MAGNETISM: properties of magnets—the Earth's magnetism—electro-magnets.

APPENDIX: Practical work on animals.

BOOK IV: CHEMISTRY: chemical theory—common elements and their compounds—carbon and some of its compounds—food-stuffs.

PHYSIOLOGY: structure and functions of living matter; nutrition, respiration, excretion, growth, movement, in plants and animals; how living things behave; reproduction in plants and animals.

MECHANICS: force, work, and energy—machines—forces in equilibrium—motion—time and space—the solar system.

ELECTRICITY: electric charges and electric currents—effects produced by electric currents—measurement of electricity—motors, dynamos, and power supplies—transformers—telegraphs and telephones—the nature of electricity—nuclear energy.

APPENDIX: table of elements.

BOOK IIIA: (HEALTH SCIENCE): Healthy living; food and nutrition. HYGIENE: of the digestive system; of the respiratory system; of the blood system; of the skeletal, muscular, and nervous systems; of the skin. The conquest of disease. Public health. Food tables.

## TEACHER'S HANDBOOK

The aims, scope, and teaching of General Science; accommodation, equipment, and laboratory management; list of apparatus, tools, and materials required; sketch-plans of science rooms; teaching methods; running notes on Books I–IV with additional experiments; bibliography; examination papers.

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Teachers will find helpful notes on various chapters of Book II on pp. 92–111 of the *Teacher's Handbook* that accompanies *General Science for Tropical Schools.*

# PREFACE TO THE SECOND EDITION

During the fifteen years that have elapsed since these books were first published, General Science teaching has expanded rapidly, and over a million copies of these books have been used in oversea schools. During the same period there has been a steady improvement in the qualifications and experience of oversea science teachers, in school science equipment, and in the educational attainments (particularly in English) of oversea students following this General Science Course. At the same time, science itself has progressed; new scientific facts have emerged, and some of the older theories have been modified. Minor amendments were made in successive reprintings of the first edition, but more extensive revision had to await the preparation of this new edition. The original textbooks have had a far-reaching influence on science teaching in oversea schools, and it is hoped that this new edition will provide increasing numbers of oversea students with a better preparation for life in this scientific age.

1955

F. DANIEL

# NOTE TO PREFACE, FIRST EDITION FOURTH IMPRESSION

I wish to take this opportunity of thanking all those who helped to carry on my work and publish my books while I was a war-time prisoner in Japanese hands for three and a half years. Without their help publication would have been long delayed.

I also wish to record how much these books owe to my wife (of Malaya Command Signals, General Headquarters Far East, Singapore; taken prisoner 15th February, 1942, died in Sumatra, 25th August, 1945). But for her these books would never have been written.

March 1946

F. D.

# ACKNOWLEDGEMENTS

Thanks are due for permission to reproduce diagrams from the following books: Capstick: *Sound* (Cambridge University Press), Figs. 113, 114, 116; Frewin: *A New Experimental Science, Book I*, Fig. 32; Frewin: *A New Experimental Science, Book III*, Fig. 104; Keeble: *Life of Plants*, Figs. 67, 68, 98, 118 (all published by the Clarendon Press); Thorpe: *Faraday Books of Practical Science, Book I*, Figs. 14, 15; Irvine: *West African Botany*, Figs. 74, 76, 80, 84, 85, and 91 (both published by the Oxford University Press); Messrs. C. F. Casella & Co., Ltd., Figs. 28, 29; Exclusive News Agency, Fig. 8; Rothamsted Experimental Station, Fig. 96.

## *Explanation of New Words and Technical Terms*

In the text, the asterisk sign (*) is used to mark the first appearance of a general word that is not included in the standard vocabulary on which this course is based (and which was not used in Book I). Such words are defined in the Glossary on pp. 199–203.

The dagger sign (†) marks the first appearance of a new scientific word or technical term that has not been used in Book I. Such words are also marked (†) in the Index so that the student can refer back to where they were first used and explained in the text.

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## CHAPTER I

# LIMESTONE

In Book One we studied the two commonest substances in the world—air and water. We shall now examine some substances that are found in the Earth's crust and are of great importance in everyday life. The first of these substances is *limestone*, a rock that is found in most parts of the world, sometimes in such great quantities as to form whole ranges of mountains. We shall try to find out something about the chemical composition of limestone and the substances that can be made from it.

### WHAT HAPPENS WHEN LIMESTONE IS HEATED?

Most people know that when limestone is strongly heated *quicklime* is formed. Let us examine this change in the laboratory.

(i) Take about 5 c.cm. of water ($1\frac{1}{2}$ in. in a $\frac{5}{8}$-in. test-tube) and add a few drops of red litmus solution. Add a little crushed limestone and shake.

What happens? ....................................

(ii) Repeat the experiment with a little limestone that your teacher has heated white-hot with a blow-pipe† flame.

What happens? ....................................

It is clear that the quicklime obtained by heating limestone is a new substance with entirely different properties. We have now to explain what happened during the heating. Perhaps the limestone combined with part of the air (like magnesium burning in air) or perhaps it lost something (like mercuric oxide on heating). The *balance* will provide the answer, for if the limestone has combined with something it will weigh more, and if it has lost something it will weigh less, after heating.

## IS THERE ANY CHANGE IN WEIGHT WHEN LIMESTONE IS HEATED?

Make an open spiral of nichrome wire (by wrapping it round a pencil) and bend the ends so that it will hang from a retort-ring, as shown in Fig. 1. Put a suitably shaped small piece of limestone inside the spiral and weigh the limestone and wire resting inside a crucible. Then replace the wire spiral and the limestone on the retort-ring and support the crucible just below them so as to catch any bits that may fall. (See that the base of the retort stand and the bench-top are quite clean so that you can see whether any bits fall outside the crucible during the experiment.) Heat the limestone as strongly as possible for at least 5 minutes. After the stone has been heated white-hot throughout, allow it to cool for a few minutes and then put the wire and the quicklime in the crucible and weigh them again. (Afterwards keep the crucible and its contents for the next experiment.)

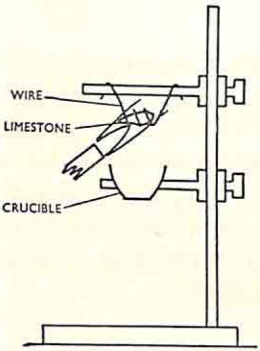

FIG. 1. Heating limestone white-hot.

Weight of crucible and wire and limestone ..........gm.

Weight of crucible and wire and quicklime..........gm.

Hence there is a decrease in weight, showing that the limestone has lost something. As we did not *see* anything escape, we conclude that a *gas* has been driven off. We shall identify* this gas in a later experiment. In the meanwhile, let us find out what happens when quicklime is 'slaked'.

## WHAT IS THE ACTION OF WATER ON QUICKLIME?

Take your weighed crucible, wire, and quicklime from the last experiment, and carefully add 5 drops of water so as to 'slake' the quicklime. Then put the crucible on a hot sand-bath so as to drive off any free, uncombined water (being careful not to lose any lime by 'spitting'). When the slaked lime is quite dry, allow the crucible to cool and then weigh it again.

Weight of crucible and wire and quicklime ...........gm.
Weight of crucible and wire and slaked lime...........gm.

Hence there is a gain in weight, showing that the quicklime has *combined* with some of the water to produce slaked lime. We know that this water must be *chemically combined* with the quicklime; otherwise it would have boiled away when the slaked lime was heated above 100° C. on the sand-bath.

Hence QUICKLIME + WATER ⟶ SLAKED LIME

### WHAT GAS IS SET FREE WHEN LIMESTONE IS HEATED?

In order to examine the gas given off when limestone is heated, we shall have to heat the limestone inside a vessel of some kind.

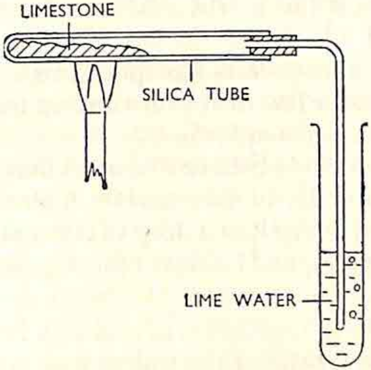

FIG. 2. Heating limestone in silica tube.

As it is not possible to heat the limestone strongly enough inside ordinary glass vessels, your teacher will do it for you by putting some crushed limestone in a narrow *silica* (or quartz) tube, which will stand a very high temperature without melting. One end of the silica tube is closed, and the other is fitted with a delivery-tube leading into some lime-water, as shown in Fig. 2.

What happens? ...........................................
What is the gas? .........................................

Hence LIMESTONE $\xrightarrow{heat}$ QUICKLIME + CARBON DIOXIDE

## WHAT IS THE CHEMICAL NATURE OF QUICKLIME?

Put a little quicklime into about 10 c.cm. of water (3 in. in a $\frac{5}{8}$-in. test-tube) and shake. Filter the milky suspension. Take about 5 c.cm. of the clear filtrate in a test-tube, breathe into the tube, then close the mouth of the tube with your thumb and shake.

What happens? ..........................................

What was the filtrate?..........................................

This should remind you of an earlier experiment when we burnt *calcium* in oxygen, producing a white solid, *calcium oxide* (Book One, Chap. III). This formed a milky suspension when shaken with water, and, after filtering, the clear filtrate became 'chalky' with expired air. This makes us think that quicklime is calcium oxide. To find out if this is true, burn a piece of metallic calcium over a crucible lid.

Does the calcium oxide look like quicklime?.................

*After cooling*, add a few drops of water to the calcium oxide so as to change it into *calcium hydroxide*.

Does the calcium oxide behave like quicklime?...............

Take a small quantity of this calcium hydroxide on the end of a clean nichrome wire, dip it in a drop of concentrated hydrochloric acid (on a watch-glass), and hold it in the edge of the non-luminous Bunsen flame.

What happens? ..........................................

Repeat this with a little of the slaked lime you have made from limestone.

What happens? ..........................................

Dip one corner of a piece of limestone in the concentrated hydrochloric acid, and hold it in the edge of the Bunsen flame.

What happens? ..........................................

*This red flame-coloration is given by all calcium compounds.*

## WHAT IS THE CHEMICAL NATURE OF LIMESTONE?

We can now summarize what we have discovered about the chemical composition of limestone:

(1) *Limestone, on heating, yields quicklime and carbon dioxide.*

(2) *Quicklime is calcium oxide.* (We synthesized calcium oxide and found that it had exactly the same properties as the quicklime obtained by heating limestone.)

(3) *Quicklime* (calcium oxide) *combines with water to form slaked lime* (calcium hydroxide), *which is slightly soluble in water. Lime-water is a saturated solution of calcium hydroxide.*

(4) *Since limestone is a compound of calcium oxide and carbon dioxide, its constituents are calcium, carbon, and oxygen, and its chemical name is calcium carbonate.*

It is also possible to synthesize calcium carbonate from the elements, calcium, carbon, and oxygen. When calcium is burnt in oxygen, calcium oxide is formed, and when carbon is burnt in oxygen, carbon dioxide is formed. When this carbon dioxide is brought into contact* with the calcium oxide, calcium carbonate is formed, with exactly the same properties as powdered limestone.

When we use lime-water as a test for carbon dioxide, we are also synthesizing calcium carbonate, for the carbon dioxide combines with the calcium hydroxide, forming calcium carbonate and water. This calcium carbonate, being insoluble in water, becomes suspended in the form of tiny white particles, thus giving a 'chalky' or 'milky' appearance to the liquid. This is also an easy way of preparing very finely powdered pure calcium carbonate, which is called 'precipitated† chalk'. (In chemistry, the verb '*precipitate*' means 'cause matter in solution to be thrown down or deposited as a solid'; the noun '*precipitate*' means the solid thus deposited.)

## WHERE IS CALCIUM CARBONATE FOUND IN NATURE?

*Limestone*, *marble*,† and *chalk* (but not 'blackboard chalk') are natural forms of calcium carbonate. Other natural forms are egg-shells, snail-shells,† sea-shells, and coral.† If a small quantity of any of these materials is strongly heated in a silica tube, as in an earlier experiment (see Fig. 2), carbon dioxide is given off and a white solid is left in the tube. When water is dropped on this solid (after cooling), there is a hissing* noise, it swells up, becomes very hot, and then breaks up into a white powder. It also colours the

Bunsen flame red; hence the substance must be quicklime (calcium oxide) and the original material must have been *calcium carbonate*.

*Chalk* was formed at the bottom of the sea, from the skeletons of tiny sea-animals. One reason for believing this is that if a very thin slice* of chalk rock is examined under the microscope it is seen to consist mainly of tiny shells. If some mud from the bottom of the sea is examined under the microscope, it is seen that this mud also contains tiny shells similar to those found in chalk. Owing to changes in the Earth's crust, some of the chalk deposits from the bottom of the ocean have been raised above the surface and are now found as soft chalk rocks (e.g. the 'White Cliffs of Dover'). *Limestone* is the commonest natural form of calcium carbonate. It is made up of small animal skeletons, but often contains larger shells and corals. Having been compressed and sometimes heated, it is often very hard. *Marble* is an even harder form of calcium carbonate. Changes in the Earth's crust have brought some of the deposits of limestone and marble to the surface, forming, in some countries, whole ranges of mountains. Chalk and limestone are still being formed at the present day. Shell-forming animals still live in the sea, building up the hard parts of their bodies from calcium compounds dissolved in the sea-water. When they die, their skeletons sink to the bottom as mud, which later forms rock.

In warm, shallow seas, the coral animal forms *coral*, which is another form of calcium carbonate, e.g. the Great Barrier Reef off the north-east coast of Australia.

### WHAT IS LIMESTONE USED FOR?

The natural forms of calcium carbonate are of great importance in everyday life. Limestone and marble have been used as building materials for thousands of years. Marble, which consists of very tiny crystals of calcium carbonate, resists the action of the weather very well, but it is too expensive for ordinary use. It is often used as an ornamental building stone. Limestone is also used in obtaining metallic iron from iron ore.

Very large quantities of limestone and chalk are used for making quicklime. In the simplest type of *lime-kiln*,† lumps of limestone or chalk are packed into the kiln, as shown in Fig. 3, and a fire is lighted at the bottom. The heat of the burning fuel decomposes the limestone, leaving quicklime. This quicklime is then used for making slaked lime.

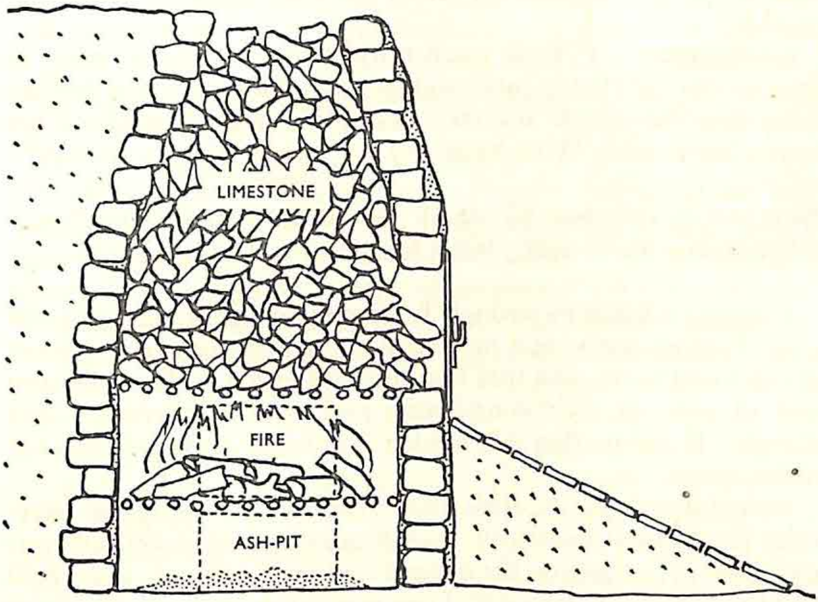

FIG. 3. Simple lime-kiln.

If slaked lime is shaken up with plenty of water, the suspension is called '*milk-of-lime*'.† If the undissolved calcium hydroxide is allowed to settle to the bottom, the clear liquid on top, which can be poured off, is a saturated solution of calcium hydroxide, or *lime-water*.

*Lime-mortar*† and *lime-plaster*† are made by mixing slaked lime with sand and water. Most of the water soon evaporates, leaving a porous material that hardens after a few days owing to combination between the slaked lime in the mortar and carbon dioxide from the air, forming calcium carbonate. The sand makes the mixture porous, so that air containing carbon dioxide can enter. For the same reason, *whitewash*† (or *lime-wash*),† a thick suspension of slaked lime in water, hardens when exposed to the air. If some old mortar, plaster, or whitewash is treated with dilute hydrochloric acid, it 'fizzes'* vigorously, giving off large quantities of carbon dioxide.

(*Demonstration.*) Your teacher will make a small quantity of lime-mortar by mixing sand, slaked lime, and water. Put a small quantity of this 'fresh' mortar in a test-tube and add a little dilute hydrochloric acid. What happens? ........................

..........................................................

Next lesson, examine the 'dried' mortar and repeat the test with dilute hydrochloric acid. What happens? ....................

..........................................................

*Cement*† is made by strongly heating a mixture of limestone and clay. *Cement-mortar* and *concrete* are mixtures of cement, sand or gravel,† and water, and they become hard owing to the crystallization of some of their constituents and *not by absorbing carbon dioxide*. Therefore they will harden even in the absence of air, e.g. under water.

Slaked lime is the cheapest alkali; hence it is used in large quantities in chemical industries. Large quantities of slaked lime are also used in agriculture for neutralizing the acidity of 'sour' soils and for improving clay soils. Lime makes the tiny particles of clay cling together in 'crumbs',* so that the soil becomes more porous and thus more easily drained.

## WHAT IS THE ACTION OF ACIDS ON CARBONATES?

(i) Put a little crushed limestone in a test-tube and add about 5 c.cm. of dilute hydrochloric acid ($1\frac{1}{2}$ in. in a $\frac{5}{8}$-in. tube).

What happens? ........................................

Put a lighted wooden splinter in the mouth of the test-tube.

What happens? ........................................

Close the mouth of the test-tube with a cork carrying a delivery tube leading into lime-water, as shown in Fig. 4.

What happens? ......................

......................................

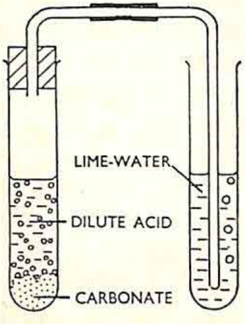

FIG. 4. Action of acids on carbonates.

(ii) Repeat the experiment with limestone and dilute nitric acid.

What happens? ......................

......................................

(iii) Repeat the experiment with dilute sulphuric acid.

What happens? ......................

......................................

(iv) Repeat the experiment, using dilute hydrochloric acid and (*a*) marble, (*b*) snail-shell, (*c*) egg-shell, (*d*) coral, (*e*) washing-soda (sodium carbonate crystals), (*f*) copper carbonate,† (*g*) lead carbonate,† (*h*) zinc carbonate,† (*i*) magnesium carbonate.† What happens?

(*a*) ..........................................................
(*b*) ..........................................................
(*c*) ..........................................................
(*d*) ..........................................................
(*e*) ..........................................................
(*f*) ..........................................................
(*g*) ..........................................................
(*h*) ..........................................................
(*i*) ..........................................................

*All carbonates give off carbon dioxide when treated with dilute acids.* This reaction gives us a very simple *test for carbonates.*

Most carbonates give off carbon dioxide even when the acid is cold, but a few, such as magnesite† (magnesium carbonate) and siderite† (iron carbonate),† 'fizz' only when the acid is warm. Carbonates and sulphides are the only natural minerals that 'fizz' with dilute acids, and it is therefore easy to identify them 'in the field', away from a laboratory. (You will remember that hydrogen sulphide can be recognized by its characteristic smell, so it is easy to tell sulphides from carbonates.)

### WHAT IS THE PERCENTAGE OF CARBON DIOXIDE IN CALCIUM CARBONATE?

We could find the percentage* of carbon dioxide in calcium carbonate by strongly heating a weighed piece of limestone and finding the loss in weight, but in order to do this accurately we should have to put the limestone in a crucible and heat it in a furnace* to make sure that the limestone was completely decomposed. It is much easier to find the weight of carbon dioxide given off when the calcium carbonate is treated with an acid in the apparatus shown in Fig. 5.

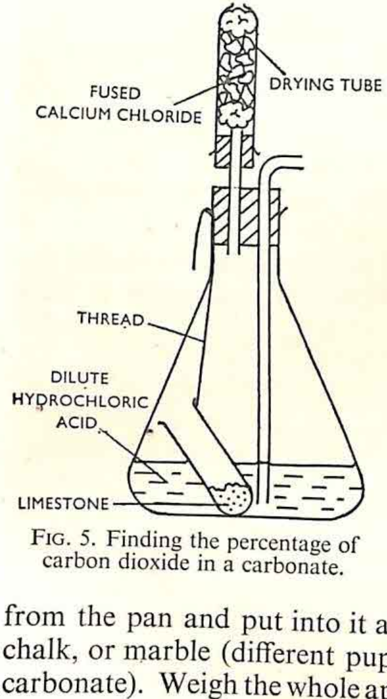

FIG. 5. Finding the percentage of carbon dioxide in a carbonate.

Half-fill the flask with dilute hydrochloric acid (75 c.cm., from the bottle marked 2N). See that the outside of the flask is clean and dry, put in the cork, and then weigh the apparatus with its empty test-tube and piece of thread on the balance-pan by the side of the flask. After weighing, remove the test-tube from the pan and put into it about 3 gm. of powdered limestone, chalk, or marble (different pupils using different forms of calcium carbonate). Weigh the whole apparatus again. Then take the apparatus to your bench and place the tube containing the carbonate *carefully* inside the flask, holding it by the thread. Replace the cork and incline* the apparatus so that the acid reaches the carbonate and begins to dissolve it, giving off carbon dioxide. Incline the apparatus again from time to time to allow more acid to reach the carbonate, but do not allow the reaction to become too rapid.

The carbon dioxide that is given off escapes through the drying-tube, where the fused calcium chloride absorbs any water vapour. When all the carbonate has dissolved, *suck* out the carbon dioxide left in the flask, through a piece of rubber tube attached* to the drying-tube, replacing it with air. (The apparatus was full of air before the experiment, therefore it must be full of air, and not carbon dioxide, for the final weighing.) Notice the *taste* of carbon dioxide as you suck out the gas. Weigh the apparatus again and enter your results below:

Weight of flask and acid and ................ ........gm.
Weight of flask and acid and empty tube...... ........gm.
Therefore, weight of...................... = ........gm.
Weight of complete apparatus *before* reaction ........gm.
Weight of complete apparatus *after* reaction.. ........gm.
Therefore, weight of carbon dioxide given off = ........gm.
Therefore, ........ gm. of ........... lose ..........gm. of carbon dioxide.
Therefore, 100 gm. of ................. lose ..........gm. of carbon dioxide;
i.e. .............. contains ........ per cent. of carbon dioxide. (Class average = ........ per cent.).

HOW TO PREPARE SOME CALCIUM CHLORIDE

Pour into an evaporating dish the clear solution obtained from your last experiment by dissolving calcium carbonate in hydrochloric acid. Add another lump of limestone (to make sure that no acid remains uncombined) and evaporate to dryness on a sand-bath. Pick out the lump of limestone when 'fizzing' stops. What is left? ..........................................

Allow the dish to cool and examine the residue at the end of the lesson.

What has happened? ..................................

The white solid is *calcium chloride*, and in its fused form (anhydrous calcium chloride) it is used for drying gases, because it readily absorbs water vapour; e.g. it is used to dry the air inside laboratory desiccators.

## CARBON DIOXIDE

In Book One we learnt that carbon dioxide is always present in the atmosphere to the extent of about 0·03 per cent. by volume, and that it is produced (*a*) *by the burning of fuels and substances that contain carbon*, (*b*) *by the breathing of animals and plants*, and (*c*) *by the decay of animal and plant remains.*

In the laboratory, while at work on Book One, we prepared small quantities of carbon dioxide, (i) by burning carbon in oxygen, (ii) by burning various fuels in air, (iii) by breathing, and (iv) by the decay of organic matter. More recently we have obtained carbon dioxide by strongly heating calcium carbonate and by treating carbonates with acids. This last method is the usual way of preparing carbon dioxide in the laboratory.

### HOW TO PREPARE SEVERAL JARS OF CARBON DIOXIDE

Carbon dioxide is usually prepared in the laboratory by the action of dilute *hydrochloric acid* on limestone or marble. (Sulphuric acid is not used because it coats the calcium carbonate with insoluble calcium sulphate,† thus stopping the reaction.)

Fit up the apparatus shown in Fig. 6 and put into it some small pieces of limestone or marble. (N.B.—*Slide* the pieces of stone very carefully into the glass vessel: *do not drop them in.*) Add water until the bottom end of the thistle-funnel is just covered, and then pour in concentrated hydrochloric acid until the gas comes off steadily. Collect three test-tubes and three gas-jars full of carbon dioxide by *downward delivery*. (We collected oxygen and hydrogen over water, but as carbon dioxide is moderately soluble in water we do not collect it over water.) You will not be able to *see* when the jar is full of carbon dioxide, but you can *test* whether the jar is full by putting a lighted wooden splinter in the mouth of the jar. If the jar is full, the flame goes out as soon as you dip the splinter into the mouth of the jar. After collecting these tubes and jars of the gas, bubble carbon dioxide for some time through a mixture of about 5 c.cm. of lime-water and 5 c.cm. of water in a test-tube, while you are doing the following experiments. Keep this tube and its contents for a later experiment.

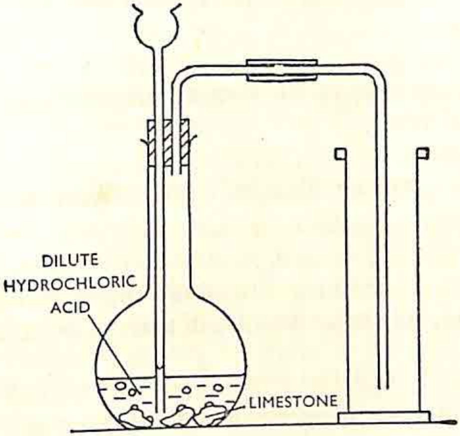

FIG. 6. Preparation of carbon dioxide.

*1st Tube.* Describe the appearance and smell of the gas. (You have already tasted the gas in your experiment on pp. 10-11.)....

.................................................................

*2nd Tube.* Invert this tube of gas in a dish of water coloured purple with neutral litmus solution.

What happens? ......................................

Why? ...................................................

*3rd Tube.* Invert this tube of gas in a dish containing dilute sodium hydroxide solution (caustic soda).†

What happens? ......................................

Why? ...................................................

*1st Jar.* Pour the gas carefully into another jar that is dry and 'empty' (as though you were pouring water) and then test both jars with a lighted wooden splinter.

What happens? ....................................

...................................................

...................................................

Why? ................................................

*2nd Jar.* Set fire to a little petrol in a crucible lid and carefully pour over it, from a gas-jar, some carbon dioxide.

What happens? ....................................

Why? ................................................

*3rd Jar.* Lower a piece of burning magnesium ribbon into the jar of carbon dioxide.

What happens? ....................................

Shake up the residue with a little dilute hydrochloric acid.

What happens? ....................................

What is left? .......................................

If ever you are asked how you would prove that carbon dioxide contains carbon, this experiment will provide the answer.

## WHAT IS THE ACTION OF CARBON DIOXIDE ON LIME-WATER?

While you have been carrying out the previous* experiments, carbon dioxide has been bubbling through the diluted lime-water in your test-tube. You will have noticed that the lime-water first turns 'chalky', but that, after a time, *it becomes clear again.* The first cloudiness is due to the formation of a precipitate of *insoluble calcium carbonate.* When more carbon dioxide is passed through this suspension, the insoluble calcium carbonate combines with carbon dioxide and water to form *soluble calcium bicarbonate,*† which dissolves, forming a clear solution. Hence, *calcium carbonate dissolves in water containing carbon dioxide.* This fact has very far-reaching results in limestone districts (see p. 17). Shell-forming sea-animals and coral animals get their supply of calcium carbonate from the calcium bi-carbonate that is dissolved in sea-water.

Divide your clear solution of calcium bi-carbonate into two parts. Boil one half for several minutes, until you see no further change.

What happens? . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

Shake up the other half with a little soap solution (5 c.cm. of 1 per cent.).

What happens? . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

Shake up the same amount of soap solution with the same volume of distilled water or rain water.

What happens? . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

Water that does not lather* readily with soap is called '*hard water*'.† We shall refer to these facts again later when we deal with '*hardness of water*'.

## THE PROPERTIES OF CARBON DIOXIDE

Carbon dioxide is a colourless gas with a very faint smell and a slightly sour taste. It is moderately soluble in water, forming a weak acid: *carbonic acid.* At 15° C. a litre of water in an open vessel contains as much dissolved carbon dioxide as a litre of the air above it. ('Soda-water'† is a solution of carbon dioxide in water, under pressure. Your teacher will demonstrate this for you by putting a cork carrying a delivery tube in a bottle of soda-water and passing through lime-water the gas that escapes.) Carbon dioxide is a 'heavy' gas (one and a half times denser than air and twenty-two times denser than hydrogen). It is fairly easily changed into a liquid by pumping the gas into strong steel cylinders under great pressure, and it is sold in this form for making 'fizzy' drinks. Liquid carbon dioxide is fairly easily frozen to a solid. Blocks of solid carbon dioxide are sold under the name of 'dry ice'† because they change directly into carbon dioxide gas on evaporation, without passing through the liquid state. Since every gram of solid carbon dioxide that evaporates takes in twice as much heat as a gram of ordinary ice on melting, this 'dry ice' is a very useful cooling agent, especially as, unlike ordinary ice, it leaves no liquid residue.

Carbon dioxide does not itself burn and it does not support combustion (except of vigorously burning magnesium or potassium). For this reason it is used in some *chemical fire extinguishers*,† such as those used in laboratories and kitchens for putting out small fires (e.g. of burning oil or fat) when water must not be used (see Fig. 7 A). The steel cylinder C contains liquid carbon dioxide under great pressure. When the handles at H are pressed together a valve opens and carbon dioxide gas rushes out through the funnel F, which is directed downwards over the burning material so as to displace the surrounding layer of air with carbon dioxide, thus extinguishing the flames.

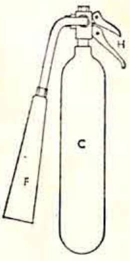

FIG. 7 A. Carbon-dioxide fire extinguisher.

In the '*soda-acid*' type shown in Fig. 7 B, when the extinguisher is needed to put out a fire (but *not* one of burning oil or due to an electrical wiring fault, where the use of water may be dangerous) the acid-bulb* is broken by hitting the metal knob and the sulphuric acid reacts vigorously with the bi-carbonate solution, liberating carbon dioxide which forces liquid out of the delivery tube, covering the burning material with the reacting mixture. Another similar type contains pure water and has a steel bottle of liquid carbon dioxide in place of the acid-bulb, so that non-corrosive water is discharged instead of a chemical solution. The '*foam* extinguishers*' used for fires involving petrol and oil work on the same principle but have a foam-producing compound mixed with the water. This produces, on discharge, about twelve times its own volume of foam, which floats on top of the burning oil and clings to any burning woodwork nearby.

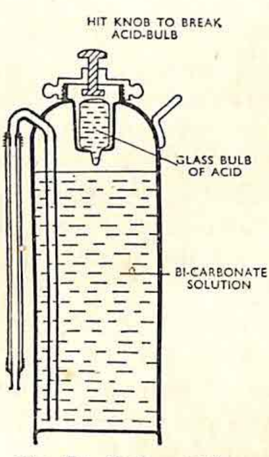

FIG. 7 B. Soda-acid fire extinguisher.

A different type of hand-extinguisher, often carried on motor-cars, pumps a jet of chemically inactive liquid, *carbon tetra-*

*chloride*,† over the burning material (e.g. burning petrol or rubber-covered electrical wiring). The heat of the fire changes the carbon tetrachloride (whose boiling point is 77° C.) into a very 'heavy' vapour which acts like a fire-proof blanket in keeping air away from the burning material.

*Carbon dioxide is not a poisonous gas*, although it may cause death by *suffocation* if it is present in large quantities. Thus a mouse* placed in a jar of carbon dioxide is suffocated owing to lack of oxygen, just as it will be drowned if put in a jar full of water: for the water kills by drowning, i.e. by suffocating, but it is not poisonous.

## HARD AND SOFT WATER

Natural waters can be divided into two classes—*soft waters*† and *hard waters.*

*Soft water gives a lather at once with soap.* Rain-water and distilled water are soft. They lather at once with soap.

*Hard water does not give a lather readily with soap*, but first forms an insoluble layer on the surface, only giving a lather when much soap has been added. Spring-water or well-water from limestone districts is hard; sea-water is very hard.

The *hardness* of water may be either *temporary** or *permanent.** *Water in which the hardness can be removed by boiling is said to be temporarily hard water. Water in which the hardness is not removed by boiling is said to be permanently hard water.*

Temporary hardness is due mainly to the presence of calcium bi-carbonate in the water. Permanent hardness is due mainly to the presence of calcium sulphate in the water.

### HOW DOES WATER BECOME HARD?

Most natural waters, except rain-water, contain some dissolved mineral matter, and these substances, dissolved from the earth, make the water hard.

We have seen already that, although calcium carbonate is insoluble in pure water, it is soluble in water that contains carbon dioxide, because the insoluble calcium carbonate is changed into soluble calcium bi-carbonate. Now rain, as it falls through the air, dissolves carbon dioxide, and when it reaches the ground, if it happens to fall on limestone, it dissolves a little calcium carbonate, forming a solution of calcium bi-carbonate.

In many parts of the world, *caves* have been formed in limestone rocks by the action of water containing carbon dioxide, continued for many thousands of years. In such limestone caves, water, dripping* from the roof, loses a little carbon dioxide, and leaves a deposit of calcium carbonate behind when it falls. Every drop of water, as it falls from the roof of the cave, leaves a little more calcium carbonate, and so the deposit grows. The hanging pieces of calcium carbonate, formed in this way, are called *stalactites*† (see Fig. 8).

CALCIUM CARBONATE + WATER + CARBON DIOXIDE $\rightleftarrows$ CALCIUM BI-CARBONATE

This reaction is *reversible*. When calcium carbonate dissolves in water containing carbon dioxide (i.e. carbonic acid), the reaction proceeds from left to right, and calcium bi-carbonate is formed. But when the clear solution of calcium bi-carbonate is boiled, the reaction proceeds from right to left, and the calcium bi-carbonate decomposes into calcium carbonate, carbon dioxide, and water. Hence, if the hardness of a sample of water is due to calcium bi-carbonate, it is easily removed by boiling, i.e. *temporary hardness can be removed by boiling*.

Some natural waters, however, contain *calcium sulphate*, and this is a cause of *permanent hardness*, for the calcium sulphate is not decomposed by boiling.

### WHAT ARE THE DISADVANTAGES OF HARD WATER?

(i) *Hard water wastes soap*. When hard water is used for washing, much soap is wasted before any lather is formed. Hence, people whose water supply is 'hard' will waste many pounds of soap in a year. This wasted soap is used up in softening the hard water before a lather can be formed.

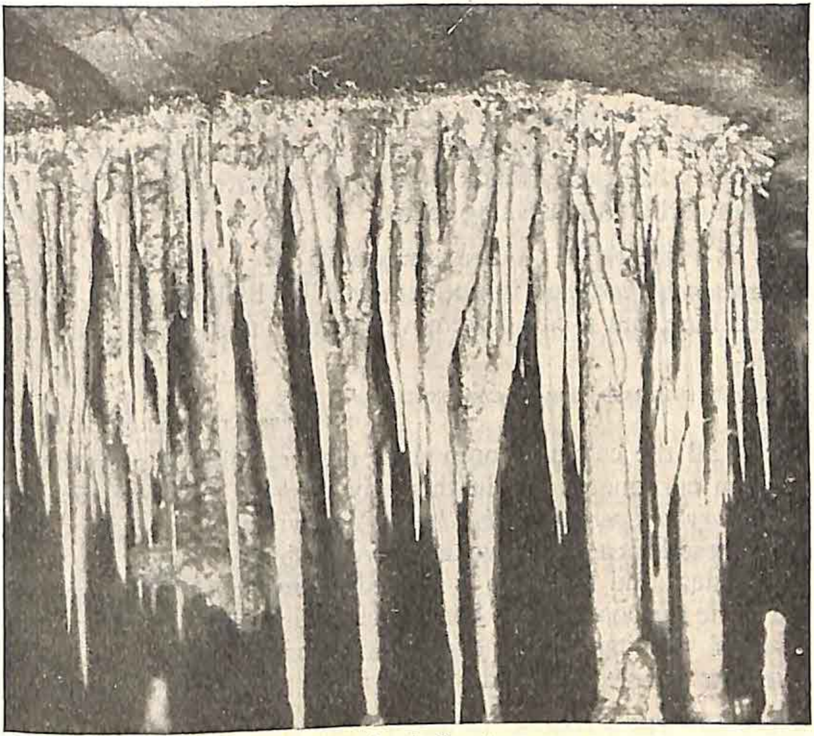

FIG. 8. Stalactites in limestone cave.

(ii) *Hard water forms 'boiler scale'.*† If hard water is used in a boiler for producing steam, the dissolved calcium compounds form a hard deposit on the inside of the boiler and boiler tubes. This is known as *boiler scale.* Besides blocking up the boiler tubes, it wastes fuel, for it is also a bad conductor of heat. If the boiler scale is not removed, the boiler may even burst.

HOW IS TEMPORARY HARDNESS REMOVED?

We have seen that *boiling* will remove *temporary hardness*, but this method can only be used on a relatively small scale. Large quantities of temporarily hard water can be softened by adding

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*just enough slaked lime* to combine with the dissolved carbon dioxide, and calcium carbonate then settles out from the water. This method is not suitable for household use, because it is first necessary to analyse the water and then calculate how much calcium hydroxide is required. The easiest way of removing the temporary hardness from a few gallons of water is to add a little sodium carbonate (washing soda).

### HOW IS PERMANENT HARDNESS REMOVED?

*Permanent hardness* is not removed by boiling or by adding slaked lime, but it can be removed by adding sodium carbonate. Thus:

CALCIUM SULPHATE + SODIUM CARBONATE ⟶
CALCIUM CARBONATE + SODIUM SULPHATE

Hence all the calcium compounds are precipitated as insoluble calcium carbonate, and in this way *washing soda removes both temporary and permanent hardness*. You will now understand why washing soda is added to water *before* washing clothes. The water is softened, and less soap is needed. *Ammonia* is also used for the same purpose. Some commercial washing powders are mixtures of washing soda and powdered soap. The new 'soapless' *detergents*† are less affected by hard water than are ordinary soaps.

### WHAT ARE THE DISADVANTAGES OF VERY SOFT WATER?

(i) Very soft water, e.g. rain-water, is rather tasteless, and most people find that slightly hard water is pleasanter to drink. A small quantity of calcium compounds in drinking-water also supplies material for the formation of bones and teeth. Very soft water does not contain enough calcium compounds for this. (Green vegetables and milk are the most important sources of calcium compounds for this purpose.)

(ii) If the water supply is very soft, lead pipes cannot be used, because soft water dissolves a little lead and so causes *lead poisoning*. Hard water does not attack lead pipes. (In a country where water supplies are soft, *iron* or *plastic* pipes are used for carrying drinking-water.)

EXPERIMENTS WITH HARD AND SOFT WATER

(1) Measure out with a graduated cylinder 50 c.cm. of *rain-water* into a clean, stoppered bottle. Add 1 per cent. *soap solution*, a few drops at a time, from a burette, shaking the bottle vigorously after each addition. Then allow the bottle to stand and notice whether a lather is formed. Go on adding soap solution until a lather is formed that lasts for at least one minute. Then read from the burette how much soap solution has been added, and record your figure below.

(2) Repeat this with 50 c.cm. of the given hard water, and record how much soap solution is required to give a permanent lather.

(3) Boil 50 c.cm. of the given hard water for 5 minutes in a flask. When cool, return it to the bottle, and add soap solution as before. (Boiling, of course, removes any temporary hardness.)

(4) Measure out 50 c.cm. of the given hard water into a beaker, and add a few crystals of *washing soda* to remove both temporary and permanent hardness. Stir to dissolve, allow to stand for 15 minutes, and then filter into your stoppered bottle and add soap solution as before.

(5) Repeat Experiment (1) with 50 c.cm. of tap-water.

Enter your results in the following table:

*Volume of soap solution required to give a permanent lather with various kinds of water*

| 50 C.CM. OF: | C.CM. OF SOAP SOLUTION REQUIRED: |
|---|---|
| RAIN-WATER | |
| TAP-WATER | |
| HARD WATER | |
| BOILED HARD WATER | |
| HARD WATER AFTER SOFTENING WITH SODA | |

Learning Exercises on Chapter I will be found on pp. 28–37 of *General Science Workbook I.*

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## CHAPTER II

## COMMON SALT

We shall now study another substance with which we are familiar in our everyday life—*common salt*—and some important substances that can be prepared from it.

Very large quantities of common salt are present in the Earth's crust. Sea-water contains, on the average, 3 per cent. of it, so there are millions of tons of common salt in the oceans of the world. (In fact, it has been estimated that there is enough salt in them to form a layer about 100 ft. thick over the whole surface of the Earth.) In some inland seas that are drying up because their loss by evaporation exceeds their gain from rain-fall the percentage of common salt is much higher. For example, the water of the Dead Sea, in Palestine, contains about 9 per cent. of salt (so much, in fact, that it is crystallizing out on the shores). Solid deposits of *rock-salt*† are common in many countries, e.g. England (in Cheshire), India, Germany, and Poland (where the bed of rock-salt is said to be 500 miles long, 20 miles wide, and about 1,000 ft. thick). It is believed that these rock-salt deposits were formed by the drying-up of inland seas millions of years ago, just as the Dead Sea is drying up today.

Rock-salt can be mined like other minerals, but it is often pumped up in solution, either from a natural salt spring, or by first forcing water down a bore-hole into the bed of rock-salt, and then, after the water has become saturated with salt, pumping up the *brine*† and evaporating it in large, shallow pans. In hot places with a long dry season, e.g. Aden, salt is got by evaporating sea-water in shallow pools by the Sun's heat. In very cold countries, e.g. around the White Sea, in Russia, most of the water is removed by freezing and the concentrated solution of salt that is left unfrozen can then be evaporated to dryness over a fire.

Common salt crystallizes in transparent* *cubes** that contain no water of crystallization.

### WHAT IS COMMON SALT USED FOR?

Most of our food contains some common salt, and we usually add more to it. In fact, all animals need common salt, for it is present in all animal body-liquids. A man loses about 12 gm. of salt a day in his urine† and some more in his sweat, and this has to be replaced. Animals that feed on green plants get their salt from the plants they eat, while animals that feed on flesh get their salt from the blood of their victims.* If animals do not get enough salt with their ordinary food, they will travel many miles to a 'salt-lick'* to satisfy their desire for salt. Miners lose a lot of salt during sweating, and they often make a habit of drinking salty water when working under these hot conditions.

Salt is also used for preserving meat and fish. It is the source of almost all *sodium compounds*, e.g. washing soda, caustic soda, and soap. It also supplies the *chlorine* used for treating water-supplies and for other purposes. Common salt is also used for glazing* cheap earthenware.

Common salt, therefore, is a most important substance in everyday life and is used in very large quantities. It is calculated that, on the average, a man gets about 30 lb. of salt a year in his food.

We learnt a lot about the chemical nature of limestone by observing the action of heat and acids upon it. We shall now study common salt in a similar way.

### WHAT IS THE ACTION OF HEAT ON COMMON SALT?

Your teacher will show you the action of heat on common salt. When heated in a hard-glass test-tube, common salt crystals break up with a loud, crackling noise, and later, as the test-tube begins to melt (at about 850° C.), the salt melts to a clear liquid.

On cooling, the liquid solidifies and is found to taste exactly like the original common salt. This suggests that it undergoes only a physical change on heating.

### WHAT IS THE ACTION OF DILUTE ACIDS ON COMMON SALT?

Your teacher will also try the effect of adding dilute sulphuric acid, dilute hydrochloric acid, and dilute nitric acid to common salt.

What happens in each case?

(i) ..........................................
(ii) ..........................................
(iii) ..........................................

### WHAT IS THE ACTION OF CONCENTRATED SULPHURIC ACID ON COMMON SALT?

(i) Take a little common salt in a test-tube and add a few drops of concentrated sulphuric acid. (*Care!* Perhaps your teacher will add it for you.) Notice the vigorous action. A gas is given off that is invisible while it is inside the tube, but which forms a cloud when it meets the air, especially if you blow across the mouth of the tube; i.e. the gas fumes* in *damp* air. You soon notice that the gas has a *pungent** smell, i.e. it attacks the nose and throat. Hold a lighted wooden splinter near (but not inside) the mouth of the tube. The gas does not burn. Put the lighted splinter inside the tube. The flame goes out, i.e. the gas does not support combustion. Hold a piece of wet blue litmus paper at the mouth of the tube. It turns red, showing that the gas forms an acid with water. Dip a glass rod in *ammonia* solution and hold it at the mouth of the tube. White fumes are formed.

(ii) Dip a glass rod in ammonia solution and hold it near (but not inside) the open mouth of a bottle of concentrated *hydrochloric acid*. As this gives the same result, the gas set free when common salt is treated with sulphuric acid is probably the same as that which escapes from concentrated hydrochloric acid. As the two gases have the same smell, this is confirmed.* Hence the gas is *hydrochloric acid gas*, or *hydrogen chloride*. The second name shows that it is a compound of hydrogen and chlorine, and we shall prove this shortly.

HOW TO PREPARE A LARGER QUANTITY OF HYDROGEN CHLORIDE

(i) A flask is fitted with a waxed cork carrying a thistle-funnel and a delivery-tube. A layer of common salt is put in the flask (large crystals of cheap commercial salt), and sufficient concentrated sulphuric acid (*Danger!*) is poured down the thistle-funnel to cover the salt. The flask is then heated gently over a sand-bath, and the gas is collected in a *dry* gas-jar by downward delivery, as shown in Fig. 9. Collect a jar of the gas and close it with a gas-jar cover. (How can you tell when the jar is full?) Keep this jar of gas till you come to Expt. (iv).

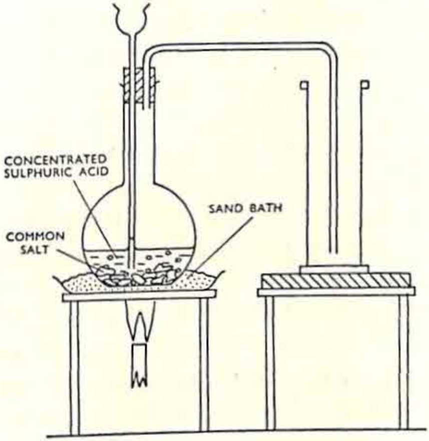


FIG. 9. Preparation of hydrogen chloride.

(ii) Fill a *dry*, round-bottomed flask or test-tube with the gas, and, when it is quite full, close the flask with a cork through which passes a glass tube to which a piece of moistened filter-paper is attached. Quickly invert the flask, with the end of the glass tube dipping under some water that has been coloured blue with litmus solution, as shown in Fig. 10. The water slowly rises up the tube until the first few drops have entered the flask; it then rushes up the glass tube, forming a fountain* inside, until the flask (if you filled it quite full of hydrogen chloride) is completely filled with water. This shows that the gas is extremely soluble in water (1 c.cm. of cold water will dissolve about 500 c.cm. of the gas under ordinary atmospheric pressure). As the water rushes into the flask the litmus turns red, showing that an acid has been formed.

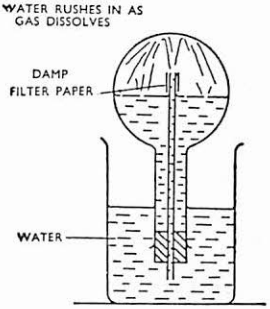


FIG. 10. Hydrogen chloride fountain.

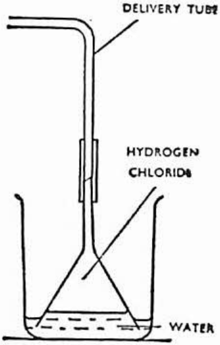


FIG. 11. Making a solution of hydrogen chloride.

(iii) Make a concentrated solution of the gas by passing it through a funnel that dips just below the surface of a *little* cold water in a beaker, as shown in Fig. 11. This device makes it impossible for the water to rush back into the flask, repeating the 'fountain experiment' in a very dangerous way! Pass the gas for a long time until the water is saturated with the gas. Notice that the solution gets warm as the gas dissolves.

(iv) While you are making a strong solution of the gas in this way, take an empty gas-jar and pour into it a few c.cm. of ammonia solution. Close the jar with a gas-jar cover and shake. Stand this jar on the bench and invert over it the jar of hydrogen chloride from (i). Remove the covers and hold the two jars mouth-to-mouth

What happens? ......................................

Leave the jars like this until near the end of the lesson and then look inside. The white solid is ammonium chloride.

AMMONIA + HYDROGEN CHLORIDE ⟶ AMMONIUM CHLORIDE

(v) Take a little of your solution of the gas from (iii) in a test-tube and put about 1 in. of magnesium ribbon into it. A gas is given off that burns with a blue flame at the mouth of the tube, or which gives an explosion if it is mixed with air. The gas is *hydrogen*. Hence, the acid gas contains hydrogen. It is true that the water also contains hydrogen, but magnesium will not set free hydrogen from cold water (see Book One, Chap. V).

(vi) Heat some more of your solution in a test-tube with a little *manganese dioxide*. A gas is given off that has a greenish-yellow colour and a pungent smell (but different from the smell of hydrogen chloride). This gas is *chlorine*. Manganese dioxide, however, contains nothing but manganese and oxygen; thus the chlorine must have come from the gas set free from salt by sulphuric acid. Hence the gas is a compound of the two elements hydrogen and chlorine, and its chemical name is *hydrogen chloride*.

(vii) Your teacher will *neutralize* some of your hydrogen chloride solution with *sodium hydroxide* solution (caustic soda), forming *sodium chloride*.

SODIUM HYDROXIDE + HYDROGEN CHLORIDE ⟶ SODIUM CHLORIDE + WATER

Taste one drop of the solution. It tastes *salty*, for *common salt* is *sodium chloride*, and the equation for the preparation of hydrogen chloride is:

SODIUM CHLORIDE + HYDROGEN SULPHATE
*common salt* *sulphuric acid*
⟶ HYDROGEN CHLORIDE + SODIUM SULPHATE

(viii) Your teacher will add a few grams of manganese dioxide to the mixture of common salt and sulphuric acid in your flask. Turn out your burner and let the hot sand heat the mixture, because you want only a little chlorine (a poisonous gas). Collect one jar of the gas as you collected hydrogen chloride, first putting a coloured flower in the gas-jar.

What happens to the flower? ..............................

Hold a piece of wet blue litmus paper at the mouth of the jar.

What happens (*a*) at first? ..............................

(*b*) finally? ..............................................

When you have prepared all the chlorine you need, put some slaked lime in the gas-jar (on top of the flower).

What happens? ..........................................

(*Caution.* Breathe as little chlorine as possible; it is *poisonous* in large quantities.)

### WHAT ARE THE PROPERTIES OF HYDROGEN CHLORIDE?

We can now summarize the properties of hydrogen chloride. It is a colourless gas that fumes in damp air. It has a pungent smell and it attacks the nose and throat. It is slightly 'heavier' than air and it is extremely soluble in water, forming a strongly acid solution—hydrochloric acid.

Hydrogen chloride does not itself burn and it does not allow things to burn in it. It turns blue litmus red and it forms solid white fumes of ammonium chloride when it comes into contact with ammonia gas. We shall examine the properties of its solution in water (hydrochloric acid) later.

We shall now prepare more chlorine and examine its properties.

## CHLORINE

We have seen that we can easily prepare hydrogen chloride from sodium chloride (common salt) by heating it with concentrated sulphuric acid; and that the gas is a compound of hydrogen and chlorine. We can set free chlorine from hydrogen chloride, therefore, if we use something that will combine with the hydrogen but not with the chlorine. We already know that oxygen will combine very readily with hydrogen, but it is not convenient to heat the two gases, hydrogen chloride and oxygen, together. Instead of this we use a substance that gives up oxygen easily, i.e. an *oxidizing agent.*† The cheapest and most convenient oxidizing agent for our purpose is *manganese dioxide*, and we shall prepare several jars of chlorine by heating *hydrochloric acid* (i.e. a solution of hydrogen chloride in water) with manganese dioxide, so that the oxygen of the manganese dioxide will combine with the hydrogen of the hydrogen chloride to form water (hydrogen oxide) and set free chlorine, forming manganese chloride† at the same time.

HYDROGEN CHLORIDE + MANGANESE DIOXIDE
→ HYDROGEN OXIDE + CHLORINE + MANGANESE CHLORIDE
*water*

### HOW TO EXAMINE THE PROPERTIES OF CHLORINE

(*Demonstration.*) Your teacher will prepare several jars of chlorine and show you some more of its properties, putting manganese dioxide in the flask and pouring concentrated hydrochloric acid down the thistle funnel, as shown in Fig. 12.

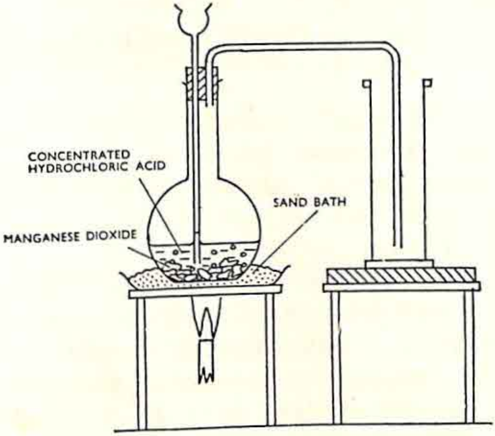


FIG. 12. Preparation of chlorine.

*1st Jar.* Notice the *greenish-yellow* colour of the gas. (This makes it easy to see when the jar is full.) When damp red and blue litmus papers are put in the gas, the blue litmus turns red for a moment and then they are both *bleached*† (i.e. the colour is destroyed). When a jet of burning hydrogen is held in the jar of chlorine, the hydrogen goes on burning, forming *hydrogen chloride*, which fumes in damp air at the mouth of the jar. The hydrogen chloride also reddens litmus (without bleaching), and forms solid white fumes with ammonia. We have therefore *synthesized* hydrogen chloride from its constituents, hydrogen and chlorine.

HYDROGEN + CHLORINE ⟶ HYDROGEN CHLORIDE

This agrees with our *analysis* of hydrochloric acid gas in an earlier experiment.

*2nd Jar.* A lighted candle is lowered *slowly* into the jar of chlorine. It *just* goes on burning, but with a reddish and smoky flame, forming fumes of hydrogen chloride and much soot (carbon). The wax of the candle contains hydrocarbons† (i.e. compounds of hydrogen and carbon), and the chlorine combines with the hydrogen of the hydrocarbons to form hydrogen chloride while the carbon is set free as soot.

A HYDROCARBON + CHLORINE ⟶ HYDROGEN CHLORIDE + CARBON

*3rd Jar.* A piece of glass-wool, soaked in petrol, is lighted and lowered into the jar of chlorine. It goes on burning, forming hydrogen chloride and soot, because petrol is a mixture of hydrocarbons similar to those in candle-wax.

*4th Jar.* A piece of glass-wool is soaked in hot *turpentine* and dropped into the jar of chlorine. It takes fire of itself, forming hydrogen chloride and soot as before, because turpentine is another hydrocarbon (but containing a very large proportion of carbon). The last four experiments show that *chlorine has a great chemical attraction for hydrogen.* Not only does it combine directly with hydrogen, but it will even take it away from other compounds.

*5th Jar.* A small piece of metallic *sodium* is melted in a gas-jar spoon and lowered into the jar of chlorine. The sodium burns with a bright yellow flame, forming clouds of a white solid, *sodium chloride*, i.e. we have *synthesized* harmless common salt from the two dangerous elements sodium and chlorine. This is a very good illustration of the statement that *the properties of a chemical compound are quite different from those of its constituents.*

*6th Jar.* A strip of thin *copper* sheet is heated and then lowered into the jar of chlorine. It catches fire of itself and there is a very vigorous reaction. *Copper chloride*† is formed, which dissolves in water to form a blue solution.

*7th Jar.* A piece of damp newspaper, which has been splashed with ordinary writing-ink, is put in the jar of chlorine. The writing-ink is *bleached* but not the printer's ink, which is made from *lamp-black* (finely divided carbon). A piece of damp red cloth and a coloured flower are also bleached by the chlorine.

*8th Jar.* The last experiment is repeated with *dry* red cloth and writing-ink. They are *not bleached*, showing that chlorine bleaches only when water is present.

*9th Jar.* Some dry *slaked lime* (calcium hydroxide) is shaken up with chlorine in a gas-jar. The colour of the gas soon disappears because the chlorine is absorbed by the lime, forming *bleaching-powder.*†

After sufficient chlorine has been collected, the delivery-tube is left dipping under some ice-water in a flask. The water gradually becomes greenish-yellow as the gas dissolves, forming *chlorine-water.*

## WHAT ARE THE PROPERTIES OF CHLORINE?

We can now summarize the properties of this very active element. Chlorine is a poisonous greenish-yellow gas that attacks the nose, throat, and lungs. It is a 'heavy' gas, nearly two and a half times denser than air, and it can therefore be collected by downward delivery. It is moderately soluble in water (1 volume of cold water dissolves 2 or 3 volumes of chlorine under ordinary atmospheric pressure) forming a greenish-yellow solution called chlorine-water. It does not itself burn, but it allows many substances to burn in it, i.e. it supports combustion. (Notice that *combustion* does not always mean 'combining with oxygen'.) Chlorine combines readily with many metals, forming chlorides, e.g. with sodium, copper, iron, tin, aluminium, and zinc. It has a great attraction for hydrogen. Hydrogen and chlorine can be mixed in the dark, but the mixture explodes when exposed to sunlight, and hydrogen chloride is formed. Moist chlorine bleaches *vegetable colours*, i.e. dyes obtained from plants. When chlorine is passed over slaked lime, it is absorbed, forming bleaching-powder, which gives up its chlorine again when treated with an acid. Chlorine is also absorbed by sodium hydroxide solution. Chlorine can be liquefied if compressed and cooled. Liquid chlorine is stored in strong steel pressure-cylinders for industrial use. Chlorine kills bacteria, and it is therefore used for destroying bacteria in drinking-water supplies (1 part of chlorine will usually kill the bacteria in two million parts of water). The water used in modern swimming-pools is also made safe by the same method. Chlorine was the first 'poison-gas' to be used by Germany in 1915, during the First World War.

### BLEACHING

Bleaching is an important process in many industries. Cloth made from plant fibres, e.g. cotton and linen,* is always a brownish colour at first and has to be bleached to give a white cloth. Years ago, cotton and linen were bleached by spreading the cloth on green grass in sunlight, when the oxygen given off by the green leaves bleached the cloth. This process was very slow, and the same result is now obtained in a much shorter time by using chlorine, usually in the form of bleaching-powder. The material to be bleached is first dipped in a suspension of bleaching-powder in water, and then dipped into dilute acid to set free the chlorine from the bleaching-powder. The bleached material is afterwards washed with water, to remove all the chlorine, which would otherwise eat away the material. Chlorine cannot be used for bleaching delicate materials like silk and wool because it damages them.

Learning Exercises on Chapter II will be found on pp. 28–37 of *General Science Workbook I*.

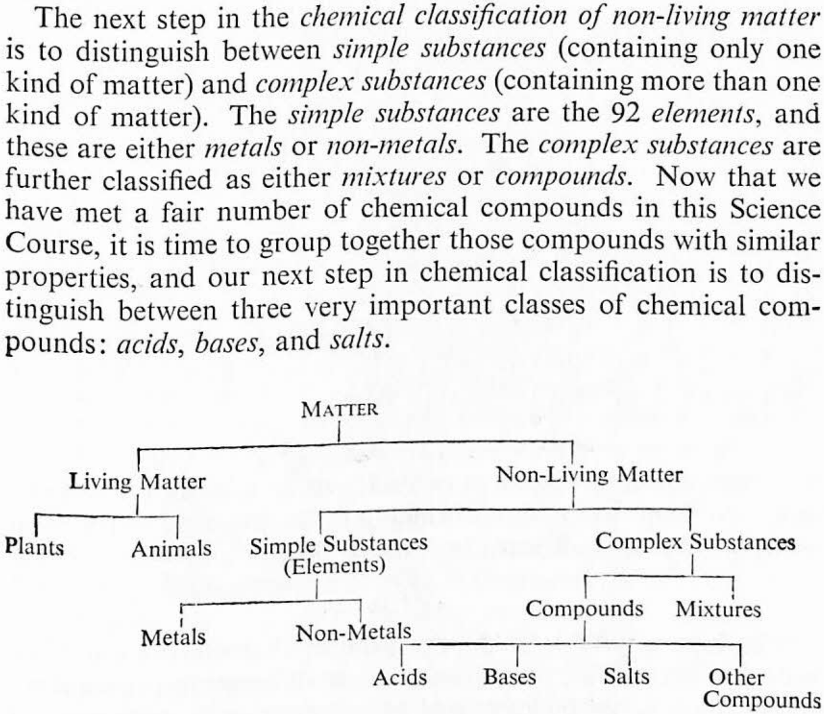
## CHAPTER III

# ACIDS, BASES, AND SALTS

### HOW ARE CHEMICAL COMPOUNDS CLASSIFIED?

We have seen that the first step in the *scientific classification* of everything in the world is to distinguish between *living* and *non-living* things. *Living things* are then divided into *plants* and *animals*.

The next step in the *chemical classification of non-living matter* is to distinguish between *simple substances* (containing only one kind of matter) and *complex substances* (containing more than one kind of matter). The *simple substances* are the 92 *elements*, and these are either *metals* or *non-metals*. The *complex substances* are further classified as either *mixtures* or *compounds*. Now that we have met a fair number of chemical compounds in this Science Course, it is time to group together those compounds with similar properties, and our next step in chemical classification is to distinguish between three very important classes of chemical compounds: *acids*, *bases*, and *salts*.



The first time that we used the terms *acid* and *base* was when we burnt a number of elements in oxygen (see Book One, Chap. III). When we burnt the *non-metals* carbon, sulphur, and phosphorus in oxygen, oxides were formed that dissolved in water, and their solutions turned blue litmus *red.* When we burnt the *metals* sodium, calcium, and magnesium in oxygen, oxides were formed that dissolved in water, and their solutions turned red litmus *blue.* This enables us to classify *oxides* into two main groups: the oxides of the *non-metallic elements* are called *acidic oxides* and the oxides of the *metallic elements* are called *basic oxides.*

The basic oxides of sodium, calcium, and magnesium all dissolved in water to form *hydroxides* that are also *alkalis*, but most other metallic oxides do not dissolve in water and so have no action on litmus. Hence, although every alkali is formed from a basic oxide, not all basic oxides can form alkalis. We can define an *acidic oxide* as *an oxide that reacts with water to form an acid*, but it is not so easy to define a basic oxide. The simplest definition of a *basic oxide* is that it is *an oxide that reacts with an acid, forming a salt and water*, e.g. copper oxide reacts with sulphuric acid to form copper sulphate (a salt) and water. The *hydroxides* of the metallic elements react in the same way with acids, forming a salt and water; hence *both the oxides and the hydroxides of metals are called bases.* We can sum up the relation between these important classes of compounds in the statement:

AN ACID + A BASE ⟶ A SALT + WATER

Notice that it is difficult at this stage to explain one of the terms *acid*, *base*, and *salt* without bringing in the other two. Later on, in Book IV, we shall learn how to do this.

### ACIDS

The best way of learning the general characteristics of acids will be to examine the properties of the acids we use most frequently in the laboratory: *sulphuric acid*, *hydrochloric acid*, and *nitric acid.*

We shall learn in later lessons how sulphuric acid is manufactured, when we study the element sulphur and its compounds in Book Four. Your teacher will demonstrate the properties of concentrated sulphuric acid, because it is one of the most corrosive* substances used in the laboratory and must be handled with great care.

Concentrated sulphuric acid is a colourless liquid that has no smell. It is much denser than water (S.G. 1·8) and it flows slowly, like a thick oil. When concentrated sulphuric acid is poured into water, much heat is produced and the solution may even boil.

When using concentrated sulphuric acid, therefore, it is important to remember (i) *never to pour water into concentrated sulphuric acid* (otherwise there may be a dangerous explosion) but to add the acid *slowly* to water, stirring all the time, and (ii) if you heat concentrated sulphuric acid in any experiment, always to *let it cool* before pouring it into the sink, and then to see that there is *plenty of water* in the sink. Concentrated sulphuric acid absorbs water very readily and it can therefore be used for drying gases. It also takes up the elements of water from many compounds that contain hydrogen and oxygen; e.g. when concentrated sulphuric acid is added to a strong solution of sugar, there is a very vigorous action: the mixture turns black and gets very hot, swelling up to form a porous mass of finely divided *carbon*. This is because sugar is a *carbohydrate*† (a compound of carbon, hydrogen, and oxygen, in which hydrogen and oxygen are present in the same proportions as in water) and the sulphuric acid removes the hydrogen and the oxygen, setting free the carbon. Concentrated sulphuric acid chars* all carbohydrates in this way, e.g. sugar, starch, cotton, paper, and wood; and this is why it attacks clothes, skin, books, and benches.

Although *dilute* sulphuric acid yields hydrogen when it reacts with many metals, *concentrated* sulphuric acid yields *sulphur dioxide* when heated with metals (because it contains such a large proportion of oxygen—65 per cent.). We shall prepare sulphur dioxide by this method in Book Four.

### HOW TO EXAMINE THE PROPERTIES OF DILUTE SULPHURIC ACID

The dilute sulphuric acid in your reagent bottles (marked 2N) is made by diluting one volume of concentrated sulphuric acid with 15 volumes of water.

(i) Add *a few drops* of *dilute* sulphuric acid to a test-tube nearly full of water, shake to mix, and then taste one drop on your finger-tip.

Describe the taste ......................................

(ii) Test this very dilute acid with blue litmus paper.

What happens? ......................................

(iii) Observe the action of dilute sulphuric acid (from the bottle marked 2N) on each of the following substances in turn, at first in the cold, and then, if there is no action, on heating. If a gas is set free, try to find out what it is. Record your observations below.

| SUBSTANCE | ACTION OF DILUTE SULPHURIC ACID |
|---|---|
| LIMESTONE<br>calcium carbonate | |
| WASHING SODA<br>sodium carbonate | |
| IRON filings | |
| ZINC | |
| MAGNESIUM | |
| LEAD | |
| COPPER | |

(iv) Add some *barium chloride*† solution and some dilute hydrochloric acid to some dilute sulphuric acid. A white precipitate† of *barium sulphate*† is formed. This reaction is a test for sulphuric acid (hydrogen sulphate) and any other *sulphate*, since barium sulphate is the only barium salt that is insoluble in dilute hydrochloric acid.

BARIUM CHLORIDE + HYDROGEN SULPHATE
*soluble* *soluble*
⟶ HYDROGEN CHLORIDE + BARIUM SULPHATE
*soluble* *insoluble*

(v) Repeat the test with solutions of (*a*) sodium sulphate, (*b*) ammonium sulphate,† (*c*) magnesium sulphate. What happens?
. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

## HYDROCHLORIC ACID

We have prepared *hydrogen chloride* by heating common salt with concentrated sulphuric acid, and we found that this gas dissolves very readily in water, forming a strongly acid solution—*hydrochloric acid.* The concentrated hydrochloric acid that is used in the laboratory is made by passing hydrogen chloride into cold water until no more will dissolve. If this solution is heated, the hydrogen chloride is driven off. (Remember this when you are doing experiments with hydrochloric acid.) The dilute hydrochloric acid in your reagent bottles (marked 2N) is made by diluting 1 volume of concentrated acid with 4 volumes of water.

## HOW TO EXAMINE THE PROPERTIES OF DILUTE HYDROCHLORIC ACID

(i) Add *a few drops* of *dilute* hydrochloric acid to a test-tube nearly full of water, shake to mix, and then taste one drop on your finger-tip.

Describe its taste . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

(ii) Test this very dilute acid with blue litmus paper.

What happens? . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

(iii) Observe the action of dilute hydrochloric acid (2N) on the following substances in turn, at first in the cold, and then, if there is no action, on heating. If a gas is given off, try to find out what it is. (Remember what happens when you boil hydrochloric acid.)

Record your observations below.

| SUBSTANCE | ACTION OF DILUTE HYDROCHLORIC ACID |
|---|---|
| LIMESTONE | |
| WASHING SODA | |
| IRON | |
| ZINC | |
| MAGNESIUM | |
| LEAD | |
| COPPER | |

(iv) Add some *silver nitrate*† solution and dilute nitric acid to some dilute hydrochloric acid. A white precipitate of *silver chloride*† is formed. This reaction is used as a test for hydrochloric acid (hydrogen chloride) or any other *chloride*, because silver chloride is the only common silver salt that is insoluble in dilute nitric acid.

$$\underset{\textit{soluble}}{\text{SILVER NITRATE}} + \underset{\textit{soluble}}{\text{HYDROGEN CHLORIDE}} \longrightarrow \underset{\textit{soluble}}{\text{HYDROGEN NITRATE}^{\dagger}} + \underset{\textit{insoluble}}{\text{SILVER CHLORIDE}}$$

Expose the suspension of silver chloride to sunlight for a few minutes.

What happens? ........................................

(v) Repeat the test with solutions of (*a*) sodium chloride, (*b*) ammonium chloride, (*c*) potassium chloride. What happens?

(*a*) ..............................................
(*b*) ..............................................
(*c*) ..............................................
...................................................

NITRIC ACID

We shall prepare some *nitric acid* in later lessons when we are studying other compounds of nitrogen in Book Four. Your teacher will demonstrate the properties of concentrated nitric acid, for it is very corrosive, attacking the skin and producing very painful sores.

Pure nitric acid is a colourless, fuming liquid with a characteristic pungent smell. When it is heated or exposed to the light for a long time it begins to decompose and turns yellow, or even brown. Concentrated nitric acid attacks the skin, wool, and silk, staining them yellow. This is because these substances contain *proteins*† (compounds of carbon, hydrogen, oxygen, *and nitrogen*, which form an important group of food materials), and we shall use this reaction in Book Four as a test for proteins. Nitric acid contains such a large proportion of oxygen (76 per cent.) that it hardly ever yields hydrogen when it reacts with metals. Copper and lead, for example, dissolve readily in concentrated nitric acid, forming nitrates, and a brown gas (an oxide of nitrogen) is given off.

### HOW TO EXAMINE THE PROPERTIES OF DILUTE NITRIC ACID

(i) Test some *dilute* nitric acid with blue litmus paper.

What happens? ......................................

(ii) Observe the action of *dilute* nitric acid on the following substances in turn, at first in the cold, and then, if there is no action, on heating.

Record your observations below.

| SUBSTANCE | ACTION OF DILUTE NITRIC ACID |
|---|---|
| LIMESTONE | |
| WASHING SODA | |
| IRON | |
| ZINC | |
| MAGNESIUM | |
| LEAD | |
| COPPER | |

### WHAT GENERAL PROPERTIES ARE COMMON TO ALL ACIDS?

Our experiments with sulphuric acid, hydrochloric acid, and nitric acid show that these acids have several properties in common; and similar experiments with other acids show that all acids have the following characteristic properties:

(i) *Acids dissolve in water.*
(ii) *Solutions of acids have a sour, 'sharp' taste.*
(iii) *Acids change the colour of litmus from blue to red.*
(iv) *Acids set free carbon dioxide from carbonates.*
(v) *Acids all contain hydrogen, which can be replaced by metals under suitable conditions.*

You will notice that we can give no simple, short definition of an acid at this elementary stage; but any substance that shows all, or most, of these properties we shall call an acid. (There are, however, some 'weak' acids that do not have *all* the properties in this list.)

## BASES

We have learnt that (*a*) *a base is a substance that reacts with an acid to form a salt and water*, and that (*b*) *the oxides and hydroxides of metals are bases*. Unlike acids, most bases are insoluble in water, and we shall first examine some insoluble bases.

### HOW TO EXAMINE THE PROPERTIES OF SOME INSOLUBLE BASES

Describe the appearance of *copper oxide*† and *zinc oxide.*† Test them with damp red and blue litmus papers.

What happens? ..........................................

Then take small quantities of each in test-tubes, and say what happens when you add to each dilute sulphuric, or hydrochloric, or nitric acid.

| SUBSTANCE | DESCRIPTION | ACTION OF LITMUS | ACTION OF DILUTE ACIDS |
|---|---|---|---|
| COPPER OXIDE | | | |
| ZINC OXIDE | | | |

### SOLUBLE BASES—ALKALIS

The bases that we use most frequently in the laboratory are soluble in water, i.e. they are *alkalis*. We shall now examine the properties of the common alkalis *sodium hydroxide* (caustic soda).

*potassium hydroxide* (caustic potash†), *calcium hydroxide* (slaked lime), and *ammonium hydroxide* (ammonia solution).

### HOW TO EXAMINE THE PROPERTIES OF THE COMMON ALKALIS

(*a*) *Sodium Hydroxide.* We shall learn in Book Four how sodium hydroxide is manufactured.

(i) Put a small piece of sodium hydroxide in an evaporating dish and watch it for a few minutes.

What happens? ....................................

(ii) Add a little water to your sodium hydroxide.

What happens? ....................................

(iii) Wet a finger-tip with the solution and rub it against your thumb. What do you notice? ....................................

(iv) Add *one drop* of your solution to a test-tube nearly full of water and taste one drop of this very dilute solution on another finger-tip.

Describe the taste ....................................

(v) Test this very dilute solution with red litmus paper.

What happens? ....................................

(vi) Pour most of your concentrated solution into a test-tube, add a little solid *ammonium chloride*, and then heat the mixture. Dip a clean glass rod in concentrated hydrochloric acid and hold it near the mouth of the tube.

What happens? ....................................

What has been formed? ....................................

(*b*) *Potassium Hydroxide.* Repeat the last six experiments with potassium hydroxide and notice that sodium hydroxide and potassium hydroxide have very similar properties. In fact, the only simple way to distinguish between them is by the *flame test.* Dip the end of a clean *nichrome wire* in your potassium hydroxide solution and hold it in the edge of a non-luminous Bunsen flame.

What happens? ....................................

Clean the end of the wire and do the same thing with your sodium hydroxide solution.

What happens? ....................................

*All sodium compounds give a bright yellow colour to the Bunsen flame and all potassium compounds give a pale purple colour to the Bunsen flame.*

(*c*) *Calcium Hydroxide*. You will remember that when water is added to *quicklime* (calcium oxide), it gets hot, cracks, swells up, and breaks up into a fine white powder—*slaked lime* (calcium hydroxide). If this slaked lime is shaken up with water, it forms '*milk of lime*', and if this white suspension is allowed to stand, the excess of slaked lime settles to the bottom, leaving clear *lime-water* on top. This lime-water is a saturated solution of calcium hydroxide. We shall now compare the properties of calcium hydroxide with those of sodium hydroxide and potassium hydroxide.

(i) Describe the taste of undiluted lime-water................

(ii) Test some lime-water with red litmus paper.

What happens? ......................................

(iii) Mix some powdered slaked lime with some solid ammonium chloride and then heat the mixture in a test-tube.

What happens? ......................................

Notice that the properties of calcium hydroxide are similar to those of sodium hydroxide and potassium hydroxide, although calcium hydroxide is not such a strong base as the other two, which are *caustic alkalis*.†

(*d*) *Ammonia*. We have seen that ammonia is set free whenever an *ammonium salt* is heated with a base. Ammonia itself is a gas, but as it is extremely soluble in water we generally use a solution of ammonia in the laboratory, and this solution is called *ammonium hydroxide*. The solution has a very pungent smell and, on heating, all the dissolved ammonia is driven off; in fact, this is the easiest way to obtain a little ammonia gas.

(i) Pour a little ammonia solution from your reagent bottle into a test-tube. Note the smell. Hold a piece of damp red litmus paper near the mouth of the test-tube.

What happens? ......................................

(ii) Dip a clean glass rod in concentrated hydrochloric acid and then hold it near the mouth of the test-tube containing ammonia solution.

What happens? ......................................

(iii) Heat the ammonia solution.

What happens? ......................................

Notice that, although ammonia has properties like those of sodium and potassium hydroxide, it is less caustic.

### WHAT PROPERTIES ARE COMMON TO ALL BASES?

Our experiments with bases show that they have several properties in common, and similar experiments with other bases show that they all have the following characteristic properties:

(i) *Bases are oxides or hydroxides of metals.*[1]

(ii) *Soluble bases have a characteristic bitter taste, their solutions feel 'soapy', and they turn red litmus blue. (They are called alkalis.)*

(iii) *Bases set free ammonia from ammonium salts.*

(iv) *Bases react with acids, forming salts and water.*

## SALTS

### NEUTRALIZATION

We have seen that most of the properties of acids are quite the opposite of those of alkalis, and when an acid is mixed with a solution of an alkali in the right proportions, the liquid that is formed shows the properties of neither acids nor alkalis; e.g. it is *neutral* to litmus, which becomes neither red nor blue, but purple. On evaporating the liquid, a substance is left that we call a *salt*. This is one way of preparing salts: by *neutralization*, i.e. by neutralizing an acid with a soluble base.

### HOW TO PREPARE SODIUM CHLORIDE BY NEUTRALIZING SODIUM HYDROXIDE WITH HYDROCHLORIC ACID

Fill a burette with *dilute hydrochloric acid* from your reagent bottle (marked 2N). Then measure out 30 c.cm. of *sodium*

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[1] Ammonium hydroxide is an exception.

*hydroxide* solution from the reagent bottle (marked 2N) with a graduated cylinder. Pour the alkali into a beaker and put a piece of litmus paper in it. Carefully neutralize this sodium hydroxide solution with dilute hydrochloric acid from the burette, adding about 20 c.cm. at first and then 1 c.cm. at a time. When the colour of the litmus changes from blue to red, stop adding acid and pour in the few drops of caustic soda left in the graduated cylinder, until the blue colour returns. Then add acid very cautiously, *drop by drop*, until the litmus is neither blue nor red, but *purple*. The solution is now *neutral* and contains neither free acid nor free alkali, i.e. the acid and the alkali have neutralized each other.

Remove the litmus paper and pour the solution into an evaporating dish. Evaporate the solution to dryness over a sand-bath, turning out the burner as soon as the liquid begins to spit. The hot sand will complete the evaporation. When dry, remove the dish from the sand-bath and allow it to cool. Taste a little of the solid residue. It is *common salt* (sodium chloride).

$$\underset{\text{acid}}{\text{HYDROGEN CHLORIDE}} + \underset{\text{alkali}}{\text{SODIUM HYDROXIDE}} \longrightarrow \underset{\text{neutral}}{\text{SODIUM CHLORIDE}} + \underset{\text{neutral}}{\text{WATER}}$$

Write down the acid and alkali you would use for making each of the following salts:

| SALT | ACID | ALKALI |
|---|---|---|
| SODIUM CHLORIDE | HYDROCHLORIC ACID | SODIUM HYDROXIDE |
| POTASSIUM NITRATE | | |
| AMMONIUM SULPHATE | | |
| SODIUM NITRATE† | | |
| POTASSIUM SULPHATE† | | |
| AMMONIUM CHLORIDE | | |
| POTASSIUM CHLORIDE | | |

When the required base dissolves in water, it is easy to make the salt by neutralizing this alkali with the proper acid. But when the base does not dissolve in water, other methods have to be used.

OTHER METHODS OF MAKING SALTS

Although most bases are insoluble in water, they all react with acids to form salts; hence another method of preparing salts is *by dissolving a base in an acid.*

HOW TO PREPARE SALTS FROM BASES

Write down the base and the acid you would use to make the following salts:

| SALT | BASE | ACID |
|---|---|---|
| COPPER SULPHATE | COPPER OXIDE | SULPHURIC ACID |
| LEAD NITRATE | | |
| MAGNESIUM CHLORIDE | | |
| ZINC SULPHATE | | |
| COBALT CHLORIDE | | |
| CALCIUM NITRATE† | | |

HOW TO PREPARE COPPER SULPHATE FROM COPPER OXIDE AND DILUTE SULPHURIC ACID

Measure out 20 c.cm. of dilute sulphuric acid from your reagent bottle (marked 2N) into an evaporating dish and heat it gently on a sand-bath. Add copper oxide, a little at a time, stirring after each addition, until no more will dissolve. Evaporate the solution over the sand-bath until crystals begin to appear round the edge, and then filter the hot solution into a beaker and set aside to cool. Crystals of copper sulphate are formed.

$$\underset{\textit{base}}{\text{COPPER OXIDE}} + \underset{\textit{acid}}{\text{SULPHURIC ACID}} \longrightarrow \underset{\textit{salt}}{\text{COPPER SULPHATE}} + \text{WATER}$$

HOW TO PREPARE SALTS FROM CARBONATES

All carbonates react with acids, forming salts and setting free carbon dioxide. This gives us another useful method of preparing salts. Write down the carbonate and the acid you would use to make the following salts:

| SALT | CARBONATE | ACID |
|---|---|---|
| LEAD NITRATE | LEAD CARBONATE | NITRIC ACID |
| CALCIUM CHLORIDE | | |
| COPPER SULPHATE | | |
| ZINC CHLORIDE | | |
| CALCIUM NITRATE | | |

## HOW TO PREPARE LEAD NITRATE FROM LEAD CARBONATE AND DILUTE NITRIC ACID

Measure out 20 c.cm. of dilute nitric acid from your reagent bottle (marked 2N) into an evaporating dish and heat it gently on a sand-bath. Then add lead carbonate, a little at a time, until no more carbon dioxide is given off. Filter the hot solution into a beaker and set it aside to cool. Crystals of lead nitrate are formed on cooling.

LEAD CARBONATE + NITRIC ACID ⟶ LEAD NITRATE + WATER + CARBON DIOXIDE

## HOW TO PREPARE SALTS FROM METALS

We have seen that some metals will displace hydrogen from dilute acids, forming salts, e.g. zinc, iron, and magnesium with hydrochloric or sulphuric acid. We have already prepared zinc sulphate in this way, as a by-product from the preparation of hydrogen. Some metals will *combine directly* with a non-metal to form a salt, e.g. sodium with chlorine, copper with chlorine.

## HOW TO PREPARE INSOLUBLE SALTS AS PRECIPITATES

Many salts are insoluble in water and cannot be prepared by the action of acids on bases, carbonates, or metals. They can be prepared, however, as *precipitates*, e.g. when a solution of barium chloride is mixed with a solution of sodium sulphate, a precipitate of barium sulphate is formed and sodium chloride remains in solution. The insoluble barium sulphate can be filtered off.

Write down the soluble salts whose solutions you would mix in order to precipitate the following insoluble salts:

| INSOLUBLE SALT | SOLUBLE SALT | SOLUBLE SALT |
|---|---|---|
| BARIUM SULPHATE | BARIUM CHLORIDE | SODIUM SULPHATE |
| SILVER CHLORIDE | SILVER NITRATE | SODIUM CHLORIDE |
| CALCIUM CARBONATE | | |
| LEAD CHLORIDE† | | |

Learning Exercises on Chapter III will be found on pp. 28–37 of *General Science Workbook I.*

## CHAPTER IV

# GENERAL PROPERTIES OF SOLIDS, LIQUIDS, AND GASES

In some of our earliest experiments in Book One we showed that air is a form of *matter* because *it has weight and occupies space.* These are two of the general characteristics of all matter.

We also know that matter can exist in *three states*: as a *solid*, or as a *liquid*, or as a *gas*. Solids are *rigid*, i.e. they have a definite shape and size (or volume) and they resist any change of that shape and size. Liquids and gases do not resist forces that change their shape, and they are classed together for scientific purposes as *fluids*, i.e. matter that can *flow*. Liquids, however, resist change of size (or volume), gases do not. We can put everything in the world into one of these three classes: solids, liquids, and gases.

### WHAT IS MATTER MADE OF?

Over 2,000 years ago some of the great Greek thinkers suggested* that matter is not continuous but must be made up of extremely small particles with empty spaces between them. That is, if a piece of any substance were divided and subdivided, again and again, into smaller and smaller pieces, the Greeks thought that the process of subdivision could not go on for ever. They argued that the process must come to an end when the material had been separated into its smallest, indivisible particles. Less than 150 years ago, this idea was again put forward by scientists to explain how chemical elements combine together to form compounds. As a result of much experimental work since that time, scientists now know that matter is made up of very tiny particles called *molecules*† and that these molecules themselves are built up of still smaller particles called *atoms*.† In the same substance all the individual* molecules are exactly alike. Thus every one of the millions of water molecules in a single drop of water is exactly like all the others. No one has ever *seen* a single atom or molecule, even with the most powerful microscope, but our knowledge of the facts of chemistry and physics, learnt from experiment, leaves no doubt that atoms and molecules do exist, and scientists have measured their weight and size and can also count them. For example, it is known that there are more molecules in one cubic inch of air than there are people in the whole world.

Everything that we know about the properties of matter fits in with this *theory** that atoms and molecules actually exist although we cannot *see* them. To give some idea of the relative size of atoms, it has been calculated that, if a drop of water were magnified* to the size of the earth, the atoms of hydrogen and oxygen in it would be about as big as oranges.

Each *element* is made up of its own kind of atom, and there are only 92 different kinds of atoms in Nature. On the other hand, there are countless different kinds of molecules. The molecules of an *element* are made up of atoms all of the *same* kind, e.g. a molecule of oxygen contains two atoms of oxygen. The molecules of a *compound* are made up of two or more atoms of *different* kinds, e.g. the water molecule contains two atoms of hydrogen combined with one atom of oxygen.

*Chemical* reactions take place between atoms or molecules, and the modern definition of an atom is that it is the smallest particle of an element that can take part in a chemical change or enter into chemical combination. Until fairly recently it was believed that atoms were the smallest particles of matter and that they could not be subdivided, but we now know that chemical reactions and some physical processes can best be explained if we assume that atoms consist of still smaller particles with special properties of their own. We shall learn more about these smallest of all particles—electrons,† neutrons,† and protons†—in Book Four.

In order to explain the properties of matter we shall find that it is not enough to suppose that molecules exist; we shall also have to assume that molecules always *move* about, of themselves, independently of any outside force, and that they always *attract* one another.

## DIFFUSION† IN GASES

When a gas with a strong smell, like hydrogen sulphide, is set free at one end of a room, we are very soon able to smell the substance at the other end of the room. This happens even when there are no moving currents of air. Similarly, if we release* a gas like carbon dioxide or hydrogen into a room, chemical tests will tell us that this gas soon becomes spread throughout the air in the room.

Some of our experiments with plants (p. 113) will also suggest to us that carbon dioxide, released by respiration inside the plant, can pass through the tiny pores† in leaves and stems into the atmosphere, and, at the same time, oxygen from the atmosphere can pass into the leaves, where it is used by the plant. Thus, while one substance moves inwards through the leaf pores, another moves outwards. This rapid spreading of a gas independently of air currents is called *diffusion*.† It is explained quite easily if we assume that gases are made up of molecules that move about freely at great speed and in all directions, frequently hitting against one another, or against the surrounding solid walls, and rebounding.* This theory also explains our earlier statement that a gas has no definite shape or size but very soon fills the whole of any containing vessel.

## LIQUIDS AND MOLECULES

We know that many gases are easily changed into liquids and vice versa,* and it is reasonable therefore to believe that liquids, also, are made up of molecules. We explain the differences between gases and liquids by saying that the molecules in a liquid are not moving about so freely as the molecules in a gas and are very much closer together. Now we suppose that molecules attract one another, and in a liquid this force of attraction between neighbouring molecules has very important effects, so we have a special name for this force—*cohesion.*† The cohesion between the molecules of a liquid hinders their movements. The molecules are still free to move about, but their cohesion is sufficient* to give the liquid as a whole a definite *size*, though not a definite *shape*.

The cohesion between molecules will depend partly on their *closeness* together and partly on the mass of the molecule, and also on other properties of the molecules, which at present we can only call '*chemical attractions*'. In gases the molecules are so far apart that we can neglect cohesion.

### DIFFUSION IN LIQUIDS

If these ideas about liquids are correct, then we should be able to show diffusion in liquids also. If we *gently* pour 20 c.cm. of alcohol on top of 20 c.cm. of water in a graduated cylinder, the alcohol at first floats on top of the water, but after a very long time the two liquids become mixed even if the cylinder is kept quite still. This is because the molecules of water have diffused into the alcohol and the molecules of alcohol have diffused into the water. The mixture is still a liquid, so there must be some attraction between the different kinds of molecule, alcohol and water.

In this experiment with alcohol and water, the total volume of the final mixture is less than 40 c.cm. This must be because the molecules of one substance enter the spaces between the molecules of the other substance.

### EVAPORATION OF LIQUIDS AND SOLUTION OF GASES

At the surface between a liquid and a gas, there must be a constant interchange of molecules. All the molecules in a liquid are not moving at the same speed; there are always some moving very slowly and others moving very fast. Every now and again one of these fast-moving molecules moves upward, away from its neighbours, and unless it rebounds from a gas molecule it will escape from the liquid into the gas above. This loss of molecules from the liquid is called *evaporation.*† If the liquid is heated, more molecules will move rapidly (because we supply them with more *energy*) and more will escape into the air, that is, the liquid will evaporate more quickly.

While evaporation is going on there must also be some *solution* of the gas molecules in the liquid, because occasionally a gas molecule, moving downwards, will pass into the liquid. This explains (for example) why all natural deposits of water contain some oxygen, nitrogen, and carbon dioxide dissolved from the air above. When one of the molecules that has evaporated from a liquid passes back into the liquid again, we say that *condensation*,† rather than solution, has taken place.

## SOLIDS AND MOLECULES

Many solids can be easily changed into liquids if we heat them. We believe, therefore, that solids, also, are made up of molecules that are not much, if any, closer together than in liquids. The molecules of a solid are arranged in a regular pattern (particularly in crystalline solids) and they are very restricted* in their movements. The difference between liquids and solids is that, while the molecules of liquids can easily move over long distances, those of solids are almost fixed in position. Hence the solid has a definite *shape* and *size*. As the solid is heated, molecular movement increases, and the solid often first softens and then melts to a liquid. Some solids have a strong smell (e.g. naphthalene† in moth balls) and evaporation must be going on from their solid surfaces, but, in general, evaporation from most solids is very slow. Solids, moreover, do not diffuse into one another, except to an extremely limited extent when two highly polished flat surfaces are placed in close contact.

## HOW SOLIDS DISSOLVE IN LIQUIDS

When a lump of sugar is placed in water, it disappears from sight and it is said to *dissolve*. The sugar is still there, because we can taste it and recover all of it in solid form by evaporating the water. We must suppose that the sugar molecules in contact with water lose the regular close arrangement present in the solid crystals and move about in the spaces between the water molecules, i.e. they diffuse into the liquid.

Place a crystal of copper sulphate at the bottom of a tall jar filled with water. Cover the mouth of the jar and stand it on a firm shelf where it will not be shaken. Notice the very slow diffusion of the dissolved molecules. In time the water in the jar will become blue throughout.

### MOLECULAR MOVEMENT

In 1827 Robert Brown, a botanist,* noticed that pollen† grains from flowers (see p. 134) showed a curious irregular movement when suspended in still water and examined under a microscope. It is now known that the same sort of movement takes place when any tiny particles are suspended in a liquid, and the smaller the particles the more rapid is their movement.

Examine a drop of diluted indian ink (which is a suspension of tiny particles of carbon in water) under the microscope and notice the movement of the solid particles (which is called the *Brownian movement*†).

The molecular theory gives us an explanation of this movement. It is due to the invisible moving molecules of the liquid hitting against the visible solid particles and knocking them first in one direction and then in another.

## PROPERTIES OF LIQUID SURFACES

Cohesion between molecules has important effects at the surface of a liquid. As shown in Fig. 13, the molecule *A*, in the middle of the liquid, is attracted equally in all directions by the neighbouring molecules. Since all these forces balance one another, the molecule *A* can move freely in any direction. But the molecule *B* is attracted inwards and to each side by its neighbours, while there is no outward attraction to balance the inward pull because there are very few molecules outside (in the air). Hence every surface molecule is subject to a *strong inward attraction at right angles to the surface.*

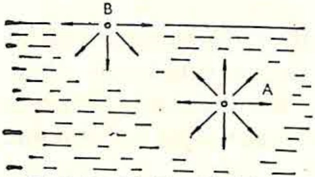

FIG. 13. Molecular forces in liquids.

This inward attraction is the cause of the tendency* of the surface to become smaller in area (because more molecules are pulled in than are moved out), and this contraction of surface continues until *the free surface is as small as possible for a given volume of liquid*, i.e. *liquid surfaces tend to contract to the smallest possible area.* Mathematicians tell us that the body with the greatest volume for a given area is a sphere; hence small drops of liquid are spherical and so are small bubbles of gases in liquids, e.g. soap bubbles.

HOW TO OBSERVE THE FORMATION OF DROPS

(i) *Demonstration.* Mix some alcohol with water until the mixture has the same density as a vegetable oil that is a little 'lighter' than water, e.g. maize oil.† Run some of this oil into the alcohol–water mixture in a slow stream from a funnel fitted with a short piece of rubber tube and a screw-clip, as shown in Fig. 14, and notice that it forms a floating drop that is perfectly spherical in shape. If the same amount of oil is run on to a smooth glass surface, it does not form a sphere because its weight counterbalances the effect due to the surface forces. Notice that a large drop of mercury on a glass plate is flattened and not spherical, for the same reason.

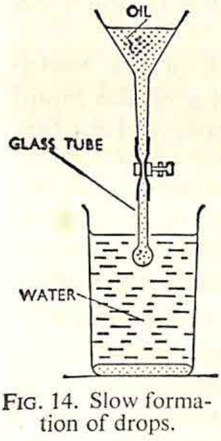

FIG. 14. Slow formation of drops.

(ii) Heat some water in a beaker until it is nearly boiling. Then turn out the burner and drop in a *naphthalene* ball ('moth ball'). Notice how the naphthalene forms a spherical drop as it melts.

(iii) Fit a funnel with a short piece of rubber tube and a screw-clip, as shown in Fig. 14. Adjust the screw-clip so that drops of water form *very slowly*. Notice how at each stage the drop approximates in shape to a sphere and finally separates from the water column when its weight overcomes the cohesion between the water molecules in the narrow 'waist'[1] (see Fig. 15).

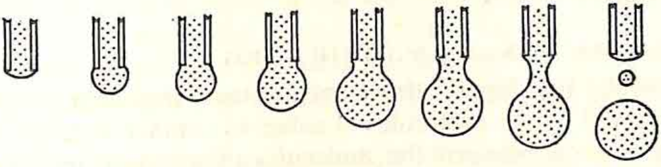

FIG. 15. Stages in the formation of a drop in air.

HOW SOAP BUBBLES SHOW CONTRACTION OF SURFACE

(i) Blow a soap bubble a few inches in diameter on the wide end of a thistle-funnel and then hold the funnel upright. If the other end of the tube is not closed by the finger, the bubble gradually contracts and finally re-enters the funnel. The soap film has reduced its surface area owing to the attraction between the water molecules.

(ii) Tie two matches together by thread as shown in Fig. 16 and stick a pin into one of the matches to form a handle. Lower this framework into a soap solution and then draw it out. Notice the contraction of the film. (We make use of this contraction of surfaces in 'rounding off' the ends of a glass tube in a flame.)

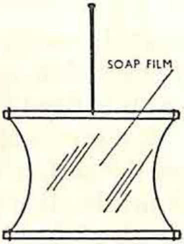

FIG. 16. Contraction of soap film.

In all experiments and observations on surfaces it is usual to talk about *surface tension*,† which may be regarded as a *measure* of the tendency for a liquid to assume the smallest possible surface area. The use of this term leads very often to the mistaken idea that there is a contracting film or skin on liquid surfaces. *There is no such*

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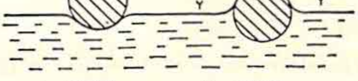
[1] Instantaneous photographs show that each 'waist' forms a tiny drop following each large drop, as shown on the right of Fig. 15.

*special film or skin on the surface of liquids*, and although later on you will have to use the term 'surface tension', remember that it is only a convenience for helping us to make certain calculations about surface forces.

## LIQUID SURFACES IN CONTACT WITH SOLIDS

Molecules in a liquid attract one another; they also attract and are attracted by the molecules of solids in contact with the liquid. This attraction between the molecules of a liquid and those of a solid is usually called *adhesion.*† The degree of adhesion determines whether a liquid wets a solid or not. Thus, a drop of mercury on a flat sheet of clean glass does not spread over the surface as a drop of water does. The water *wets* the glass (the adhesion being great) while the mercury does not. If the glass is coated with grease, it can no longer be wetted by the water, which, if placed on it, forms drops, as mercury does. We use soap, in washing our hands, largely because it allows the water to wet the skin and the particles of greasy dirt, which are then more easily rubbed away.



A GREASY (FLOATS)    B CLEAN (SINKS)

FIG. 17. Needles on water (section, enlarged).

If a greasy and therefore non-wettable needle is placed carefully on the surface of water, it will float, although the density of steel is nearly eight times that of water. It is upheld partly by the upthrust of the displaced water (see Book One, Chap. VI), and partly by an upthrust brought about by the tendency of the curved water surface under it to contract to its smallest area (i.e., in this example, to straighten out to its original shape, see Fig. 17A).

If the steel needle is wettable, it sinks; Fig. 17B gives us some idea of why this happens. The metal and the water molecules now adhere more strongly, and a cross-section through the needle shows us what the surface of the water looks like at the moment when the needle is placed on the water. The needle is upheld by the same forces as when it floats (see Fig. 17B), but now the contracting tendency of the upwardly curved surfaces $XY$ counteracts* these forces and the needle sinks. A floating needle may be made to sink if certain substances are added to the water (e.g. one of the new 'soapless' *detergents*). One of the reasons for this is that these substances make the solid more 'wettable', i.e. they change the angle of contact between the water surface and the solid, just as soap changes the angle of contact between water and particles of dirt.

Many insects can walk on the surface of water, and water-snails and mosquito larvae† can float almost totally submerged* so that they appear to be hanging from a surface skin. The explanation of this is similar to that given for the floating needle.

### CAPILLARITY

(i) Place the ends of several clean glass tubes of narrow bore (called *capillary*† tubes, from the Latin, *capilla* = a hair) upright in water (see Fig. 18A) and notice that

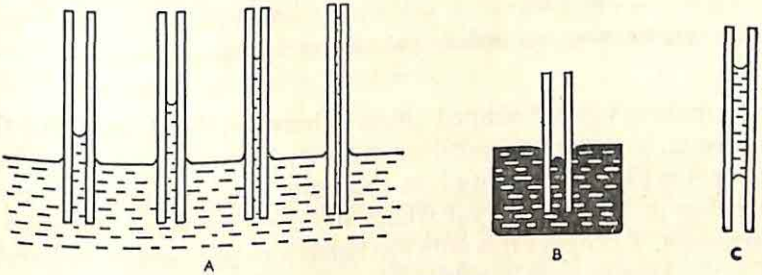


FIG. 18. Capillarity.

- (*a*) water wets clean glass;
- (*b*) the surface of the water in the tubes forms a curved *meniscus*,† concave* from above;
- (*c*) the water rises in the tubes above the level of the surrounding water;
- (*d*) the narrower the bore of the tube, the higher water rises in it.

(ii) Push the end of a fairly wide glass tube vertically into a small dish containing mercury (see Fig. 18B). Notice that

(*a*) mercury does not wet glass;
(*b*) the meniscus is convex* from above;
(*c*) the mercury in the tube falls below the level of the surrounding mercury.

(iii) Take two *clean* sheets of glass and bind them together with a rubber band, separating two vertical edges with a match-stick so as to make a wedge*-shaped space in between the sheets. Put the apparatus in a vertical position with its lower edge dipping into water (see Fig. 19). Notice how the water rises between the plates, reaching its greatest height where the space between the glass is narrowest. Compare this with the behaviour of mercury in a vessel of similar shape (see Fig. 19).

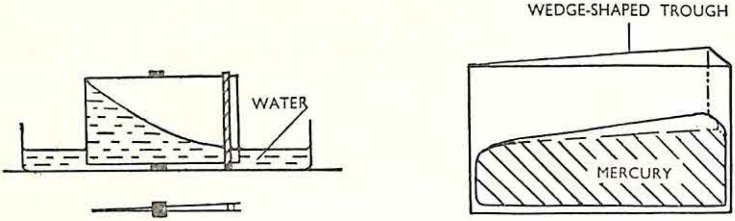


FIG. 19. Behaviour of water and mercury in wedge-shaped vessel.

The everyday rule that 'water finds its own level' does not hold good, then, in capillary tubes. Liquids that wet the surface of these tubes rise in them above the surface of the surrounding liquid. Liquids that do not wet the tubes fall below the level of the surrounding liquid (see Fig. 18).

The rise of a liquid in a narrow tube is called *capillarity*.† This is difficult to explain at this stage of our science course, and we must content ourselves with saying that the rise is connected with (*a*) the tendency of liquid surfaces to contract, owing to cohesion; (*b*) the tendency of the liquid to wet the tube walls, owing to adhesion.

The rise is limited by the force due to the weight of the liquid in the tube, and this force becomes greater as the liquid rises higher.

Capillarity is an important process in everyday life. Many materials, such as cloth, lamp wick,* blotting-paper,* bricks, mortar, soil, and lump-sugar may be looked upon as made up of thousands of interwoven capillary tubes, and all these substances will 'soak up' water by capillary action. The waterproofing of cloth used for making tents and raincoats consists in coating the material with a substance that makes the walls of the capillaries non-wettable. The rain-water then behaves like the mercury in the experiment above and does not soak into the material.

It must be remembered that water will only rise in a uniform capillary tube so long as there is a free water surface below. If there is a meniscus at each end of the tube (see Fig. 18c), then the water column remains stationary. Water will rise by capillary action in soil to a height of several feet, *but only so long as there is actual free water (and not merely damp soil) below.* Hence capillary action in ordinary well-drained soils is not nearly so important as was once thought (see also pp. 160–161).

PRESSURE

Owing to the attraction between two objects, an object standing on the ground exerts a push (or force) equal to its own weight. Now this force may be exerted over a small or a large area. For instance, let us consider a man of 150 lb. weight standing on snow. He is exerting a force of 150 lb. weight over an area of snow equal to, say, 100 square inches (the area of his boot soles*), and this is sufficient to make him sink down into soft snow. If the same man is wearing snow-shoes or skis,* he will exert the same force, of 150 lb. weight, over a much greater area, say 500 square inches, and we know that he will not sink into the snow to the same extent.

It is clear then that when discussing forces we shall often have to consider the area over which they act. The terms *stress*† and *pressure*† have therefore come into use. In the illustration given

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above, the man exerts a *force* of 150 lb. weight. When wearing ordinary boots he is exerting a *stress* or *pressure* on the snow of

$$\frac{150 \text{ lb. weight}}{100 \text{ sq. inches}} = 1{\cdot}5 \text{ lb. wt. per sq. in.}$$

When in snow-shoes, he exerts the same force, but a lower stress or pressure of only

$$\frac{150 \text{ lb. weight}}{500 \text{ sq. inches}} = 0{\cdot}3 \text{ lb. wt. per sq. in.}$$

By a stress or pressure, therefore, we mean *the force acting on unit area*. Pressures (stresses) are measured in lb. wt. per sq. in., in gm. wt. per sq. cm., etc.

## ATMOSPHERIC PRESSURE

Fluids exert stresses on all surfaces with which they are in contact, and the term *pressure* is usually reserved for *stresses due to fluids*. We are all living in a fluid, air, and the Earth is covered by a layer of air that exerts a pressure on the Earth's surface. We call this pressure the 'atmospheric pressure'. We can measure it roughly in the following way.

## HOW TO MEASURE THE PRESSURE OF THE AIR WITH A BICYCLE PUMP

We can get a rough value for the pressure of the atmosphere by using an ordinary bicycle pump. The arrangement is shown in Fig. 20. The hole in the end of the pump is closed up by means of a screw, and the cup-shaped leather washer inside the pump is reversed. A little *thick* oil is poured round the leather washer to make an air-tight joint. The pump is then clamped in a vertical position.[1]

At the beginning of the experiment, the piston† is pushed in as far as it will go, so as to displace most of the air from inside the pump. Weights are then hung from the handle of the pump. It is found that the piston does not slide down when weights of a few pounds are added, because the pressure of the atmosphere on the back of the piston and washer is too great. When just sufficient weights are added to pull down the piston, we know that their weight balances the force exerted* by the atmosphere.

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[1] As this is an unusual way of using a bicycle pump, you should first turn to p. 86, where its normal working is explained.

This weight, therefore, is equal to the force exerted by the air on an area equal to the cross-section of the pump cylinder.

*Weight supported* =........pounds weight
*Inside diameter of pump cylinder*
=........inches
Therefore, *area of cross-section of pump* ($\pi r^2$)
$= 3{\cdot}14 \times (\qquad)^2$
=......sq. in.

Hence, ........ sq. in. supports a force of ........ pounds weight.
Therefore, 1 sq. in. supports a force of ...... ÷ ...... = ...... lb. wt.
Hence, the pressure of the air is ........ lb. wt. per sq. in.

Repeat your experiment, using a pump or syringe* with a greater or smaller diameter than that already used. You will now have to hang a greater or smaller weight on the piston, but your calculation should give you roughly the same figure for the *pressure*.

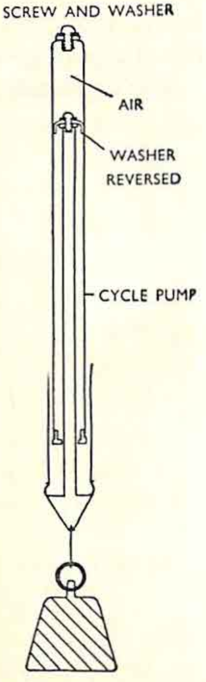


FIG. 20. Measuring the air pressure with a modified cycle pump.

Some simple and striking experiments will demonstrate the existence of this great atmospheric pressure, which we normally do not notice because it is exerted equally in all directions at any one place.

(i) A small quantity of water is put in a boiling-tube (a large test-tube) which is fitted with a cork and a glass tube as shown in Fig. 21. The water is heated over a burner until it boils vigorously and steam escapes freely from the end of the glass tube. The boiling-tube is then removed from the flame and inverted quickly, with the end of the glass tube under water in a beaker. After a few seconds, water from the beaker rushes up the glass tube and fills the boiling-tube.

The explanation of this experiment is that, when the water boils,

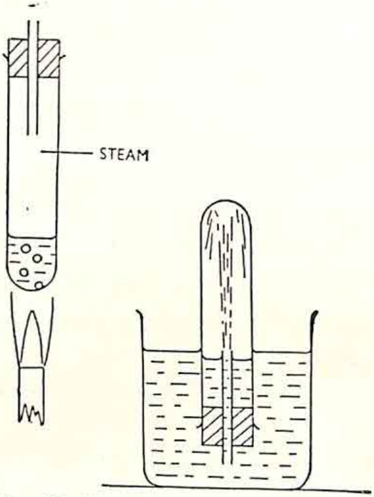


FIG. 21. Water forced into empty space by air pressure.

it forms many times its own volume of steam, and this steam drives the air out of the tube. (1 c.cm. of water forms 1,700 c.cm. of steam, or you may find it easier to remember the rough rule used by engineers, that *a cubic inch of water forms a cubic foot of steam.*) Hence, after the water has boiled for a few seconds, the boiling-tube contains nothing but steam in the space above the boiling water. When the tube cools, however, the steam changes back again into water; and, since 1,700 c.cm. of steam condense to only 1 c.cm. of water, there is a great reduction of pressure inside the boiling-tube. The outside pressure of the air on the surface of the water in the beaker therefore pushes the water into the empty vessel. The force with which the water rushes into the tube shows that the air exerts a great pressure.

(ii) A little water is poured into a tin can and boiled so as to displace air by steam (Fig. 22). When steam is escaping freely, the burner is removed, the mouth of the can is corked up tightly, and cold water is poured over it. The steam is condensed, so that there is a great reduction of pressure inside, and the pressure of the air crushes the walls of the can inwards. Notice that the walls of the can are pushed in *from all sides*, suggesting that *air pressure acts equally in all directions* and not just downwards.

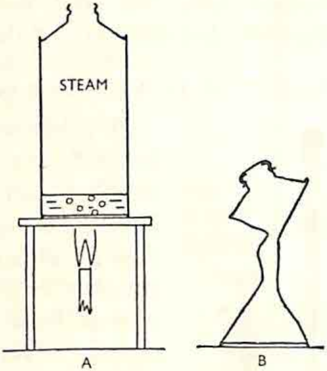


FIG. 22. Can crushed by air pressure.

(iii) A very famous experiment, which was one of the earliest proofs that air exerts a pressure, was carried out at Magdeburg in Germany, in 1654, by Otto von Guericke. He made two hollow metal hemispheres† 22 in. in diameter, which fitted together exactly. Having first showed how easily the two halves could be separated, he fitted them together to make a sphere, and then he drew out of it as much air as possible with an air-pump. It was found that the two hemispheres could no longer be separated easily; in fact, it required the pull of eight horses attached to each hemisphere to pull them apart! After the air inside had been removed, the force holding the two halves together was, of course, the pressure of the atmosphere on the outside. This demonstration apparatus is still known as the *Magdeburg hemispheres.*†

These three experiments show clearly that the air exerts a very great pressure, and it seems curious that we have not noticed this before in our everyday life. We do not usually notice the pressure of the air *because it is exerted equally in all directions* and also because *our bodies are specially adapted* to withstand this pressure.*

## HOW TO MEASURE AIR PRESSURE ACCURATELY

Since this *air pressure* is so important in everyday life, it is necessary to have some means of measuring it accurately, and the instruments used for this purpose are called *barometers*† (*pressure measurers*).

We have already carried out a simple experiment, using a bicycle pump, for measuring roughly the pressure of the air in pounds per square inch. We shall now make a simple barometer that will measure the pressure of the atmosphere accurately.

## HOW TO MAKE A SIMPLE BAROMETER

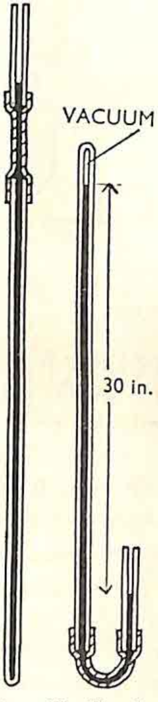


FIG. 23. Simple Barometer.

A thick-walled glass tube, about 3 feet long, is sealed* up at one end. To the other end is attached another short piece of glass tube, by means of thick rubber tubing. While the tubes are held as shown in Fig. 23, clean mercury is poured in until it stands in the shorter glass tube above the rubber. The apparatus is then bent into the shape of a J, as shown, and the tubes are held in a vertical position by means of retort clamps. It is found that the mercury in the long glass tube falls slightly, leaving *an empty space* (a *vacuum*)† between its surface and the top of the tube. There can be no doubt that the space above the mercury is a vacuum, for we first filled the tube quite full of mercury, and no air entered the long tube when the apparatus was bent into a J. Also, mercury does not evaporate readily, nor does it contain dissolved gases. If the long tube is inclined carefully until the mercury touches the end of the tube, there is a sharp metallic 'click'.* If we repeat this with a tube that contains a little air above the mercury, the mercury rebounds and there is no sharp 'click', for the air acts as a 'cushion' between the mercury and the glass. If several of these simple barometers are set up, using tubes of different diameters, the *vertical height* between the mercury surfaces in the open tube and in the closed tube is found to be the same in every case.

### HOW TO SHOW THAT THE COLUMN OF MERCURY IS SUPPORTED BY AIR PRESSURE

Early scientists thought that the vacuum in the tube 'sucked up' the mercury, and they explained the rise of liquids in tubes from which the air had been removed by saying that 'Nature hates a vacuum'.

The correct explanation is that the rise of liquids in such tubes is due to the *pressure of the air* on the surface of the liquid *outside*, as the following experiment proves.

(*Demonstration.*) A simple barometer is fitted up as shown in Fig. 24, with the open end of the barometer tube dipping under some mercury in the glass jar. The barometer tube is first filled with mercury by laying the apparatus on its side so that the air in the barometer tube is completely displaced by mercury. The barometer is then placed upright and the bent glass tube is connected to a suction* pump. As soon as some air is removed from inside the jar, the mercury surface in the barometer tube falls lower, and continues to fall as the pressure of the air inside the vessel becomes less and less. (If a perfect vacuum could be obtained inside the vessel, the mercury would stand at the same level inside and outside the tube.) When air is allowed to re-enter the vessel, the mercury rises in the barometer tube, and finally returns to its original level. This experiment shows quite clearly that *it is the outside pressure of the air that supports the column of mercury in the barometer tube.*

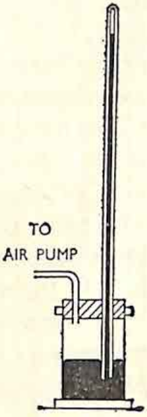


FIG. 24. Barometer connected to air pump.

### HOW TO MEASURE AIR PRESSURE BY MEANS OF A SIMPLE BAROMETER

The column of mercury inside the barometer tube is balanced by the air pressing on the surface of the mercury outside; hence the *vertical height between the two mercury surfaces* is a measure of the air pressure. It is found that the column of mercury supported by the air is usually about 30 inches (or 760 mm.) high.

If we know the density of mercury, we can easily calculate the pressure of the air in pounds per square inch. Suppose the area of cross-section of the barometer tube is *one square inch*. It will therefore contain 30 cu. in. of mercury. But 1 cu. in. of mercury weighs 7·85 ounces; therefore 30 cu. in. of mercury weigh $30 \times 7{\cdot}85 = 235{\cdot}5$ ounces $= 14{\cdot}7$ pounds. *Hence* (when the height of the barometer is 30 inches) *the pressure of the air is* 14·7 *pounds weight per square inch*, i.e. almost a ton on every square foot.

We have already found that the height of the barometric column is not affected by the diameter of the barometer tube. Suppose the area of the cross-section of the barometer tube is only $\frac{1}{2}$ sq. in. The tube will contain 15 cu. in. of mercury weighing 7·35 lb. Hence the pressure of the air measured by this narrower barometer is 7·35 lb. wt. per $\frac{1}{2}$ sq. in., i.e. 14·7 lb. wt. per sq. in. as before.

In the wider tube the force exerted by the heavier column of mercury is greater, but it is exerted over a greater area, so the *pressures* are the same in both tubes.

### AIR PRESSURE AND THE HUMAN BODY

The total surface area of an average man's body is about 10 square feet; hence the total force on his body amounts to *several tons*. We do not feel uncomfortable under this great pressure because we have become *adapted* to it; in fact, if this pressure is much reduced, we soon begin to feel very uncomfortable. For example, men that fly at great heights or that climb very high mountains, where the pressure of the air is low, have great difficulty in breathing, and may bleed at the nose, ears, eyes, and throat, because the pressure of the air at such heights is lower than the pressure of the blood.

When we breathe, we do not 'swallow' air, or 'suck in' air, as many people think, but muscles* raise the ribs* and thus enlarge the chest-cavity.* This reduces the pressure inside the lungs, and *the greater air pressure outside forces air into the lungs*. The muscles then allow the ribs to fall to their former position, thus making the chest-cavity smaller, so that the used air is forced out through the mouth and nose.

### WHY MERCURY IS USED IN BAROMETERS

Mercury is the most convenient liquid for use in liquid barometers because it is so *dense*. Other liquids could be used, but since they are all much 'lighter' than mercury, the barometer tube would have to be much longer: thus, mercury is 13·6 times more dense than water, hence a water barometer would have to be at least 30 × 13·6 inches long, i.e. about 34 *feet*, which would be most inconvenient. Therefore mercury is always used in barometers that balance the air pressure against a column of liquid.

### THE SIPHON† BAROMETER

This type of barometer, which is accurate enough for all elementary* work, is of the same pattern as the J-shaped barometer we made for ourselves, but it is fixed to a board and has a scale attached to it for measuring the vertical height between the two mercury surfaces, as shown in Fig. 25. There is usually a glass 'trap' at the bottom of the longer tube to catch any air or moisture that may enter the open end of the instrument.

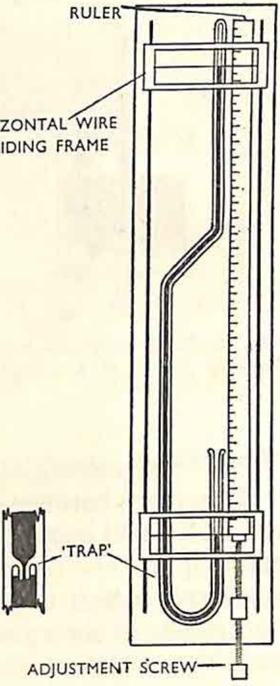


FIG. 25. Siphon Barometer (with enlarged section of air-trap).

### FORTIN'S BAROMETER (THE STANDARD BAROMETER)

When the pressure of the air has to be measured very accurately, a *Fortin's barometer*† is used. This type of barometer has a device for bringing the surface of the mercury in the trough always to the same level before a reading is taken. This is necessary because when the pressure of the air changes, the amount of mercury in the tube (and hence in the trough) changes. Therefore the bottom of this trough is made of soft leather, so that it can be raised or lowered by means of a screw until a fixed pointer just touches the surface of the mercury, as shown in Fig. 26.

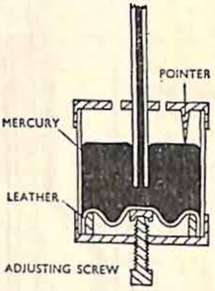


FIG. 26. Section through mercury trough of Fortin's Barometer.

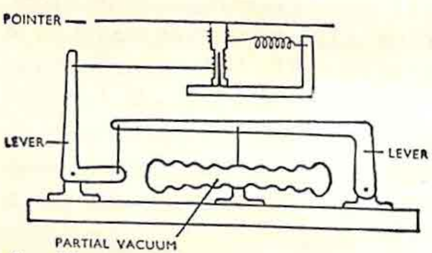


FIG. 27. Aneroid barometer (diagrammatic section).

THE ANEROID† BAROMETER

A mercury barometer is not suitable for carrying about, since it is at least 30 inches long, and besides this mercury is heavy and easily spilt. For these reasons, an instrument called an *aneroid barometer*, which contains *no liquid*, is often used. An aneroid barometer, as shown in Fig. 27, consists of a thin, round metal box from which most of the air has been removed. When the air pressure increases, the metal box becomes slightly flattened, and when the pressure decreases, it swells out. These movements are magnified several hundred times by levers* so as to move a pointer around a circular scale. Aneroid barometers can be made quite small for carrying about, e.g. surveyors* and explorers carry aneroid barometers that are no bigger than a small clock (see Fig. 28). Aneroid barometers (altimeters)† are also fitted to aeroplanes for measuring the height reached. Compare readings taken with an aneroid on the ground floor and top floor of a tall building.

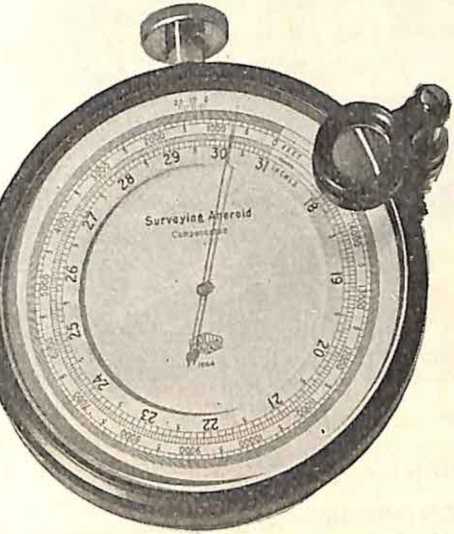


FIG. 28. Aneroid barometer, with altitude scale.

## SELF-RECORDING BAROMETERS. BAROGRAPHS†

It is not always possible or convenient to take barometer readings as often as is required, and for the purposes of weather science an aneroid barometer is fitted with a small pen in place of a pointer. This pen touches a sheet of squared paper wrapped round a revolving cylinder moved by clockwork. The cylinder usually takes a week to revolve once, so that a line is drawn on the squared paper to produce a *graph* showing all the changes of air pressure during the week. The paper is ruled in such a way that the pressure at any particular *time* can easily be read off. A self-recording barometer is shown in Fig. 29.

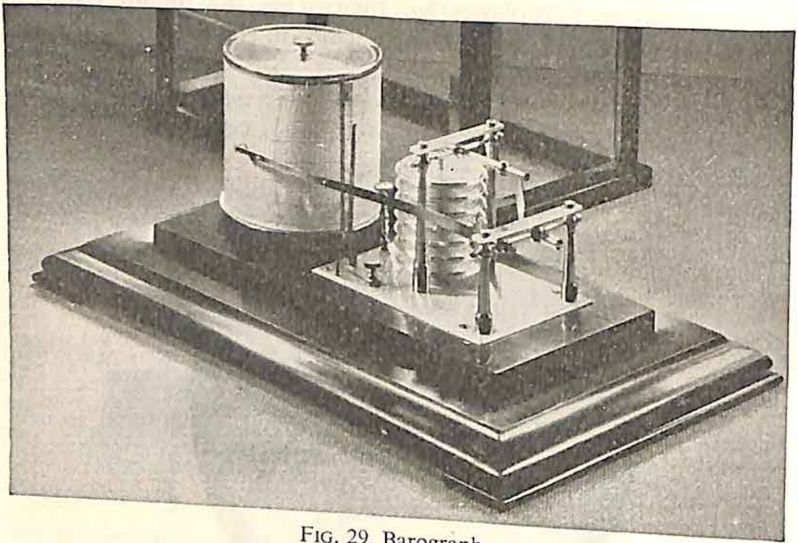


FIG. 29. Barograph.

### WHAT ARE BAROMETERS USED FOR?

A barometer is sometimes called a '*weather-glass*' because there is some connexion between changes in air pressure and the weather. But it is important to realize that it is not possible to give an accurate weather forecast* from a knowledge of the air pressure alone.

Weather is the condition of the atmosphere at any particular time, and this is also a matter of air movements, air temperature, and the amount of moisture in the air. Hence the air conditions that influence the weather at any place are (*a*) *the air pressure*, (*b*) *the air temperature*, (*c*) *the amount of water-vapour in the air* (i.e. the *humidity*† of the air), and (*d*) *the speed and direction of the wind*. It is true that when the weather is wet, the barometer is usually 'low', and when the weather is dry, the barometer is 'high'. This is because water vapour is much 'lighter' than dry air; hence, the drier the air, the greater its density. And the greater its density, the greater its pressure, so that the barometer 'rises' when the air is dry. A mixture of air and water-vapour is less dense than dry air; hence its pressure is less, and the barometer 'falls'. Thus, when 'the weather-glass goes down' we know that the air is getting damper, and that there is more chance of rain; while if 'the weather-glass goes up' we know that the air is getting drier and there is a better chance of dry weather. But the barometer alone does not enable us to say with any certainty what the weather will be: several other factors* have also to be taken into account.

We have already mentioned the use of a barometer for measuring vertical height or *altitude*.† The farther we rise vertically upward through the atmosphere, the less air is pressing down upon us, i.e. the atmospheric pressure becomes less. For the first few thousand feet, *a rise of 900 feet causes the mercury column to fall one inch*, so that this change in air pressure provides a simple means of measuring altitude. For example, if an aneroid barometer reads 30 inches on the ground and falls to 25 inches when taken up in a balloon, then the balloon is at a height of $(5 \times 900) = 4{,}500$ feet. The *altimeter* fitted in an aeroplane is simply an aneroid barometer with an altitude scale instead of the ordinary scale. Altimeters only give correct readings of height if the general atmospheric conditions remain the same during an ascent* or descent.

### WHAT IS THE UPPER LIMIT OF THE ATMOSPHERE?

The rise or fall of one inch in the height of a barometer with a change of 900 feet in altitude applies only to comparatively small altitudes of a few thousand feet. For example, if a balloon starts at sea level and goes up to 5,000 feet, and then up to 10,000 feet, the change in air pressure from 5,000 to 10,000 feet is less than the change during the first 5,000 feet. This suggests that the air must become less and less dense as we rise upwards from the ground. If air were like water, and could not be readily compressed, it would be easy to work out the height to which the atmosphere extends. For example:

taking the air pressure at the Earth's surface as 14·7 lb. wt. per square inch $(= 14{\cdot}7 \times 144 = 2{,}117$ lb. wt. per square foot),

since 1 cubic foot of air weighs about 0·08 lb.,
the depth of air required to produce a pressure of 2,117 lb. wt. per sq. ft. would be
2,117÷0·08 = 26,460 feet, i.e. about 5 miles.

We know that the air extends far higher than 5 miles because balloons and aeroplanes have risen to greater heights and they could not do this if there were no air. It is now confirmed that the atmosphere *does* extend to a much greater height than 5 miles.

We get a better idea of the actual extent of the atmosphere by observations of meteors† ('shooting stars'). As the Earth moves through space, one of these bodies may come near enough to be attracted by the Earth and fall towards it. The meteor falls towards the Earth at great speed, and, when it reaches the upper layers of the atmosphere, the *friction** of the air makes it become luminous. So, on a dark night, we begin to see it as a 'shooting star'. Careful observations show that meteors first become visible when they are about a hundred miles above the Earth's surface; hence we conclude that *the atmosphere extends upwards for about a hundred miles*, i.e. a layer of air about 100 miles in thickness surrounds the Earth.

Owing to its *compressibility*, the air becomes less and less dense according to height above the Earth's surface. We have learnt that gases are like liquids in having no definite *shape*, but that they differ from liquids in having *no definite size* (or volume). A pint of water remains one pint, no matter what size vessel it is poured into; but if any quantity of air is put into an empty, closed vessel, it will completely fill the vessel, whatever its size. In fact, it is quite easy to compress a quantity of air to a half, or a quarter, or even a tenth of its original volume, as we prove every time we pump up a bicycle tyre.*

The air at the Earth's surface is under the greatest pressure, and it is therefore most compressed there. The higher we rise in the air, the less air is above us and the less the pressure becomes. At higher levels, therefore, the air is less dense since it is not compressed so much. For example:

| HEIGHT ABOVE SEA-LEVEL | WEIGHT OF 100 CU. FT. OF AIR | BAROMETER READING |
|---|---|---|
| At sea-level | 8 lb. | 30 in. |
| At 3 miles | 4 lb. | 15 in. |
| 5½ ,, | 2 lb. | 7·5 in. |
| 10 ,, | 1 lb. | 3·75 in. |
| 15 ,, | 0·3 lb. | 1 in. |
| 35 ,, | 0·0003 lb. | 0·001 in. |

Hence, after the first few thousand feet, the density and pressure of the air decrease very rapidly with altitude.

If the air were not *elastic* (i.e. if it did not compress under high pressures and expand under low pressures), the layer of air surrounding the Earth would be all of the same density, and only about 5 miles deep. Actually, the atmosphere extends for about 100 miles above the Earth's surface and becomes less and less dense according to height. About half the air in the atmosphere is within 3 miles of sea-level and over 90 per cent. of all the air is below a height of 15 miles.

## THE COMPRESSIBILITY OF GASES

### 'THE SPRING OF THE AIR'

When dealing with the *molecular structure of matter* we learnt that the molecules of a gas are very much farther apart than those of liquids and solids; and that they are free to move rapidly in all directions so as to fill completely any containing vessel. Since the actual molecules of a gas occupy only a very small proportion of the total volume of the gas, gases are easily compressed. For example, if you close the small hole at the end of a bicycle pump with your finger, and then force the handle inwards, the air inside the pump is compressed into a smaller space; but, when you let go the handle, it flies back to its original position, showing the *elasticity* or '*spring*' of the air. (We make use of this elasticity in *pneumatic* tyres*, riding comfortably on the 'spring of the air'.)

This result can be explained from the molecular structure of matter, because the pressure of a gas is caused by the hitting of its molecules against the walls of the vessel. When we compress a gas, we pack the same number of molecules into a smaller space; hence the molecules hit the walls of the containing vessel more often, i.e. there is an increased pressure.

Robert Boyle (1627–91) was the first man to study the compressibility of gases, which he called '*the spring of the air*'. He used this term because the air seems to act like a coiled spring, which, when it is compressed, tries to expand again to its original size. Boyle was assisted by Robert Hooke, a clever young mechanic* whose name will be mentioned in other science lessons. These two made the first satisfactory *air-pump*. Using this air-pump, Boyle was able to prove that it is the pressure of the air that supports the column of mercury in the barometer tube (see p. 65).

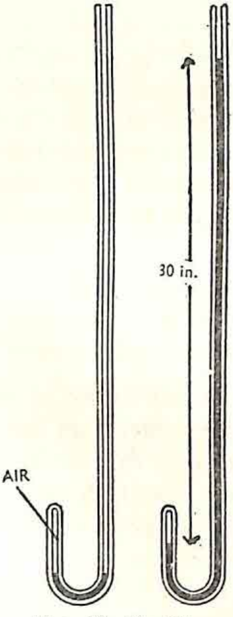


FIG. 30. Boyle's experiment.

WHAT IS THE RELATION BETWEEN VOLUME AND PRESSURE IN A GAS?

Robert Boyle measured the change in the *volume* of a gas produced by changing the *pressure* upon it. We can easily repeat one of his historic experiments.

A J-shaped glass tube has its shorter limb sealed off, and mercury is poured into the open limb until it stands at the same level in both sides, as shown in Fig. 30, i.e. the closed limb contains a certain volume of air at atmospheric pressure (30 inches of mercury). The length of this column of air is measured off. Mercury is now poured into the longer, open limb until the air in the closed limb is compressed to *half* its original volume, as shown in Fig. 30. The height of the column of mercury in the open limb is then measured, and its length is found to be 30 inches greater than that in the closed limb, i.e. *in order to halve the volume of the air, we have to double the pressure*, for the original pressure was 'one atmosphere', while the final pressure is 'two atmospheres'. ('One atmosphere' pressure equals 14·7 lb. wt. per sq. in.)

### HOW TO SHOW WITH A BICYCLE PUMP THE RELATION BETWEEN VOLUME AND PRESSURE OF A GAS

The last experiment is only suitable for pressures of up to two or three atmospheres. We can easily do similar experiments using greater pressures of several atmospheres with an ordinary bicycle pump, arranged as shown in Fig. 31. The pump is of the same size as the one used in the experiment on p. 60, the small hole in the end being closed in the same way, but the leather washer inside the pump is not reversed. A little thick oil is poured inside the pump to make the washer airtight. As the pump-cylinder is of uniform cross-section, we can measure changes in the volume of the enclosed air by measuring the length of the air column between the washer and the closed end of the pump on a ruler fixed outside the pump.

At the beginning of the experiment, the total force pressing on the enclosed air is equal to the weight of the piston and its fittings (= ........ lb. wt.) *plus* the force due to the atmospheric pressure, which we found by the experiment (with a similar pump) on p. 60 to be ........ lb. wt.

Length of column of air at start of

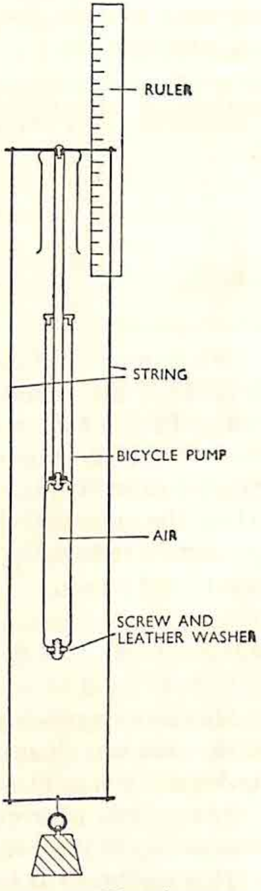


FIG. 31. Experiment to illustrate Boyle's Law.

experiment = ........ in., when the force is ........ + ........ = ........ lb. wt.

When the weight pressing on the enclosed air is doubled (= ........ lb. wt.), the air is compressed and its new volume can be measured by noting how far the piston slides down. By adding more weights, the pressure can be made three, four, and even five atmospheres.

| EXPERIMENT NUMBER | TOTAL FORCE ON PISTON IN LB. = PRESSURE ($P$) | LENGTH OF COLUMN (PROPORTIONAL TO VOLUME) ($V$) | PRODUCT $P \times V$ |
|---|---|---|---|
| I | lb. (= atmospheres) | in. | |
| II | lb. (= ,, ) | in. | |
| III | lb. (= ,, ) | in. | |
| IV | lb. (= ,, ) | in. | |
| V | lb. (= ,, ) | in. | |

When done carefully, these experiments show that if the pressure is *doubled*, the volume is *halved*: if the pressure is increased *three times*, the volume is reduced to *one-third*: if the pressure is increased *four times*, the volume is reduced to *one-quarter*: and so on. Similar experiments with other apparatus show that, conversely,* when the pressure is *halved*, the volume is *doubled*: when the pressure is reduced to *one-third*, the volume becomes *three times* as great: and so on.

### BOYLE'S LAW—THE RELATION BETWEEN VOLUME AND PRESSURE OF A GAS

Similar experiments with other gases show that *all gases behave in the same way*; hence we can state the relation between the volume and the pressure of a gas as follows:

*The volume of a given quantity of gas varies inversely* as the pressure upon it (as long as the temperature remains the same).*

This statement is known as *Boyle's Law*.† The last part of the definition is necessary since the volume of a gas changes when the temperature changes. (We shall study the effect of *temperature* on the volume of a gas in later lessons, when dealing with Charles's Law, in Book Three.)

### WHAT ARE SCIENTIFIC LAWS?

As this is the first time we have used the word 'law' in its scientific sense, it is necessary to point out the difference between *civil* laws* and *scientific laws.* In every country, the government makes certain 'civil laws' that everyone is expected to obey, and when people disobey, i.e. when the law is 'broken', the offender (if he is found out) is punished. 'Scientific laws' are quite different. *A scientific law states a fact*, e.g. Boyle's Law simply states that if the pressure on a gas increases, then the volume decreases at the same rate. So Boyle's Law states how gases *do behave*, civil laws only state how people *ought to behave.*

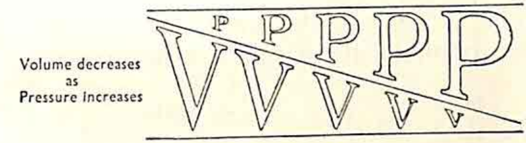


FIG. 32. Boyle's Law.

### WHAT IS INVERSE PROPORTION?

*When two quantities vary inversely, their product* is constant** (see your results for the product $PV$ on p. 76). For example, in sharing out £100 equally among a number of men, the greater the number of men, the less money per man. Or, conversely, the fewer men, the greater will be each man's share—ten men would get £10 each, twenty men would get £5 each, and five men would get £20 each. The number of men multiplied by the number of pounds is the same in each case, and the number of pounds per man is said to *vary inversely* as the number of men; or, the number of pounds per man is *inversely proportional* to the number of men.

We can also state Boyle's Law as in algebra.* If the original volume is represented by $V_1$, and the original pressure by $P_1$, and the final volume and pressure by $V_2$ and $P_2$, then $P_1V_1 = P_2V_2$.

### HOW IS BOYLE'S LAW USED?

Boyle's Law can be used to find the volume that a gas will occupy at any given pressure if its volume at some other pressure is known. For example, if a quantity of gas measures 200 c.cm. at 750 mm. pressure, find its volume at 760 mm. pressure:

By Boyle's Law: new volume × new pressure = old volume × old pressure.

Therefore (volume of gas at 760 mm.) $\times 760 = 200 \times 750$.

Therefore, the volume of the gas at 760 mm. pressure

$$= 200 \times \frac{750}{760} = 197 \text{ c.cm.}$$

(N.B.—Since the pressure will be greater, the volume will be less. In all calculations on the correction of volumes of gases for changes in pressure, always ask yourself whether the final volume will be *more* or *less*, and arrange your factors accordingly. You will thus avoid foolish mistakes.)

## PRESSURE GAUGES

Barometers are used for measuring the pressure of the atmosphere, but it is often necessary to measure the pressure of other fluids. Various types of *pressure gauges*† (or *manometers*†) are used, the kind of instrument depending on whether the pressure to be measured is large or small. The three main kinds of pressure gauges are (*a*) *vacuum gauges* for very low pressures, (*b*) *open-tube manometers* for pressures of about one atmosphere, and (*c*) *closed-tube manometers* for higher pressures.

### VACUUM GAUGES

For measuring very low pressures, like those obtained with an air-pump, a short barometer is used as shown in Fig. 33. The longer limb, which is sealed at the top, is completely filled with mercury, while the shorter limb is open at the end. The pressure on the surface A is measured by the difference in level between the surfaces A and B. (If a perfect vacuum could be obtained, these surfaces would stand at the same level.)

Enclose a vacuum-gauge in a small bell-jar connected to an air-pump, and measure the lowest pressure obtained.

Height of mercury surface in closed limb .......... mm.

Height of mercury surface in open limb .......... mm.

Therefore, column of mercury supported by air pressure = ....mm.

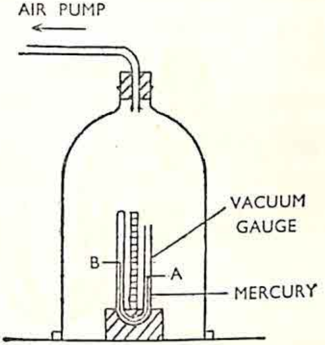


FIG. 33. Vacuum gauge.

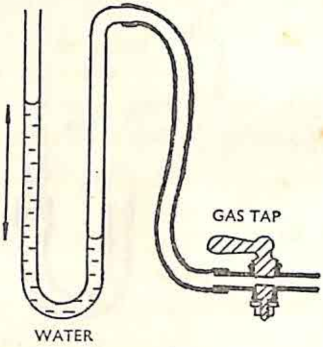


FIG. 34. Open-tube manometer.

OPEN-TUBE MANOMETERS

Pressures that are slightly greater than the pressure of the atmosphere, e.g. the pressure of the laboratory gas supply, can be measured by means of an open-tube manometer, which balances the pressure to be measured against a column of liquid, as in the *water manometer* shown in Fig. 34. A glass U-tube, open at both ends, is partly filled with water. One end of the tube is connected to the gas supply, and the difference between the level of the water in the two limbs is measured.

Height of upper level of water = .......... inches.

Height of lower level of water = .......... inches.

Therefore, column of water balanced by pressure of gas supply = .......... inches.

Hence we can say that the laboratory gas supply is under a pressure of '.......... inches of water'. (For pressures of more than a few inches of water, mercury can be used in the U-tube instead of water.)

When pressures are measured by balancing against a column of liquid, they are often expressed as heights of liquid, e.g. as 'millimetres of mercury' or as 'inches of water', instead of reducing them to 'grams weight per square centimetre' or 'pounds weight per square inch'. Remember, however, that 'a pressure of 760 mm.' really means 'a pressure that will balance a column of mercury 760 mm. high'.

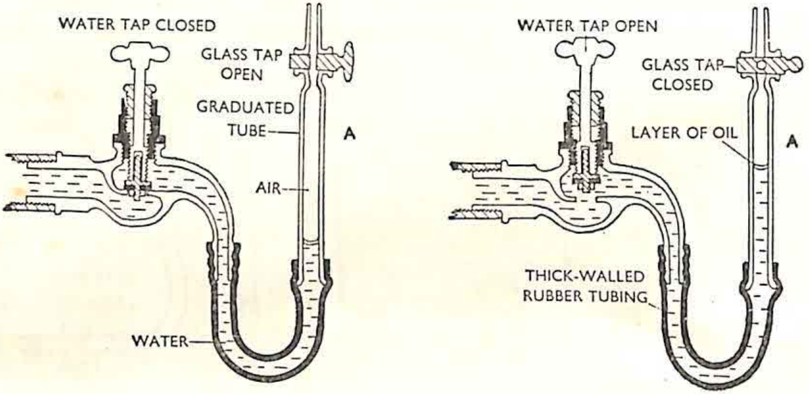


FIG. 35. Closed-tube manometer.

### CLOSED-TUBE MANOMETERS

For measuring still higher pressures we can make use of Boyle's Law, e.g. for measuring the pressure of the laboratory water supply. In the apparatus shown in Fig. 35, a thick-walled glass tube A, graduated in c.cm., is attached to the water-tap by a thick-walled rubber tube. The glass tap at the end of A is first opened and a few drops of oil are poured into the tube. (The layer of oil is to stop the compressed air from dissolving in the water.) The water-tap is then opened *slightly* until the water-level reaches the first mark on the tube A. The water-tap is then tightly closed while the volume of air inside A is read off *with the glass tap open*, i.e. at atmospheric pressure. The glass tap is then closed and the water-tap is gradually opened. The volume of the enclosed air is reduced in inverse proportion to the water-pressure; e.g. if the volume is halved, then the water pressure is 'two atmospheres'. Find the pressure of the laboratory water-supply in this way.

Volume of air in tube at atmospheric pressure = .......... c.cm
Volume of air in tube at pressure of water supply = ........ c.cm.
Height of barometer = ......... inches.
From Boyle's Law, $P_1V_1 = P_2V_2$; hence,

atmospheric pressure × volume at atmospheric pressure
= water pressure × volume at water pressure.

That is, .......... × .......... = water pressure × ..........

Therefore, water pressure = $\dfrac{\quad\times\quad}{\qquad}$ = ........ in. of mercury.

Or since mercury is 13·6 times as heavy as water this is equivalent to........ feet of water.

This experiment also enables us to find the vertical height of the water-tank or reservoir* above the tap in the laboratory.

We must bear in mind, however, that the water in the open tank or reservoir is already under a pressure of one atmosphere (= 34 feet of water) while our experiment measures *total pressure*. Hence, the height of the water surface that produces the pressure at the tap is (........ −34) feet = ........ feet.

The height (or depth) of a liquid that is producing a pressure is usually known as the '*head of liquid*'.† In the laboratory, for example, we have 'a head of ........ feet of water'.

## THE BOURDON GAUGE

Gauges for measuring very high pressures, e.g. the pressure of steam in boilers, are usually of the Bourdon† type shown in

Fig. 36. In this kind of gauge a flattened metal tube, closed at one end, is bent into a curve, so that when pressure acts on the inside of the tube, it tries to straighten out. This makes a pointer move over a scale, so measuring the pressure, usually in lb. wt. per square inch. Such gauges have to be *standardized* against known pressures. When such an engineering gauge reads 100 lb. wt. per sq. in., it usually means 100 lb. wt. per sq. in. *above one atmosphere.*

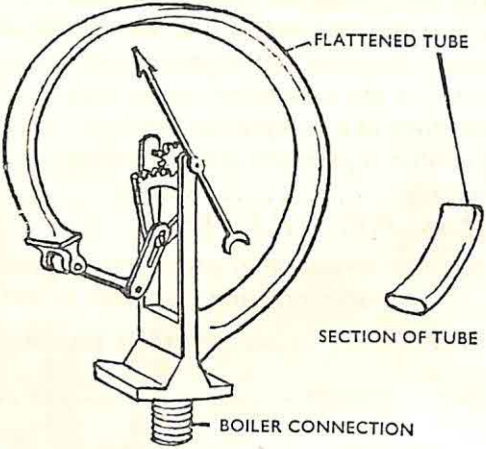


FIG. 36. Bourdon gauge.

## USES OF AIR PRESSURE

### HOW WE MAKE AIR PRESSURE DO WORK

We shall now discuss some everyday devices that make use of air pressure, e.g. *lift-pumps* and *force-pumps*, *bicycle pumps*, *automatic* brakes* on railway trains*, *siphons*, and *self-filling pens.*

### THE SYRINGE

A syringe* (or squirt)* is filled with water by the pressure of the air. The jet is held below the surface of the water, and the piston is pulled up. This increases the volume of the air inside the cylinder and so decreases its pressure. The air pressure, acting on the surface of the liquid outside, then forces water into the syringe (Fig. 37). You should note that although the water appears to be 'sucked into the syringe' it is actually *pushed in by the pressure of the air*. When the cylinder is full of water, the syringe is removed from the water, and when the piston is forced in, water is driven out of the jet.

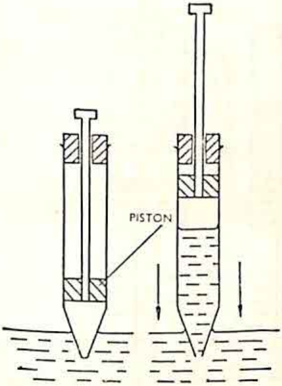


FIG. 37. Syringe.

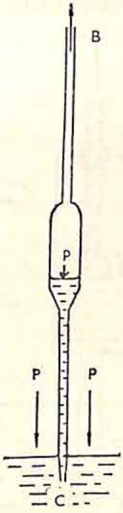


FIG. 38. Pipette.

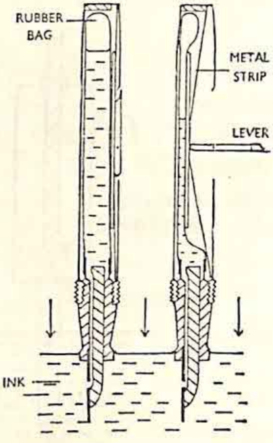


FIG. 39. Fountain pen.

### THE PIPETTE

The pipette works on the same principle, the pressure $p$ inside the pipette being reduced by 'sucking-out' air from B with the mouth. The outside atmospheric pressure $P$ being greater than the inside pressure $p$, water is pushed into the pipette, at C, see Fig. 38. (The use of a 'drinking straw' depends on the same principle.)

### THE SELF-FILLING PEN

A fountain pen, of the type shown in Fig. 39, works on the same principle as the syringe and the pipette. The body of the pen contains a long rubber bag against which rests a strip of metal. When the lever on the side of the pen is raised, the metal strip presses on the rubber bag and forces out the air from inside. When the lever is lowered, the metal strip no longer presses on the rubber bag, which now returns to its original size; thus the pressure inside the bag is reduced. If the pen-nib is dipping in ink, the air pressure on the surface of the ink forces some ink into the bag.

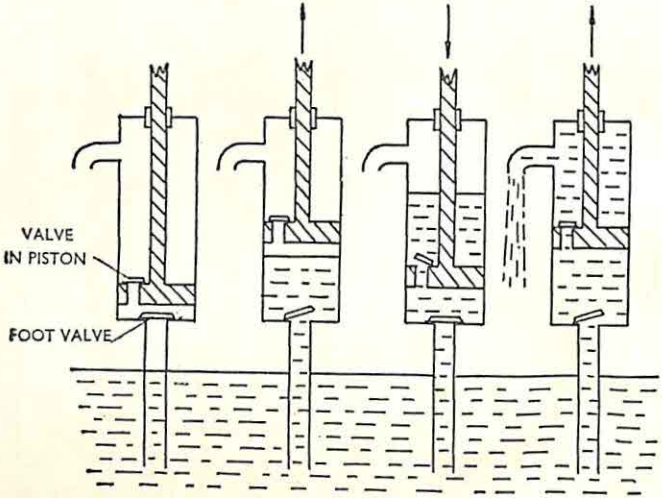


FIG. 40. Lift-pump.

### THE LIFT-PUMP

The ordinary lift-pump (also called the common pump) works on the same principle. In a lift-pump (Fig. 40) there is a piston working up and down in a cylinder; and there are two valves, one at the lower end of the cylinder, and the other in the piston. Both these valves open upwards only and thus allow water to pass upwards, but not downwards. When the piston is pulled up, the air pressure keeps the valve in the piston closed, and the pressure in the cylinder beneath the piston is reduced. Hence, as in the syringe, owing to the air pressure outside, water is forced up into the cylinder, opening the foot-valve at the bottom of the cylinder.

When the piston is pushed down, the foot-valve closes and the water inside the cylinder passes through the valve in the piston to the upper end of the piston. The next time the piston is drawn up, the valve in the piston closes and this water is forced out of the delivery-pipe, while more water enters the pump through the foot-valve. This type of pump is often called a 'suction-pump', but you should remember that it is the air pressure *outside* that forces water into the pump.

### LIMITATIONS OF LIFT-PUMPS

We have seen that water is forced into the pump cylinder by the pressure of the air, but we know that the pressure of the air can only support a column of water about 34 feet high. Hence, in theory, an ordinary lift-pump must not be more than 34 feet above the level of the water that is being pumped up. In practice, since pistons and valves cannot be made perfectly air-tight, very few ordinary lift-pumps will raise water more than 20 feet.

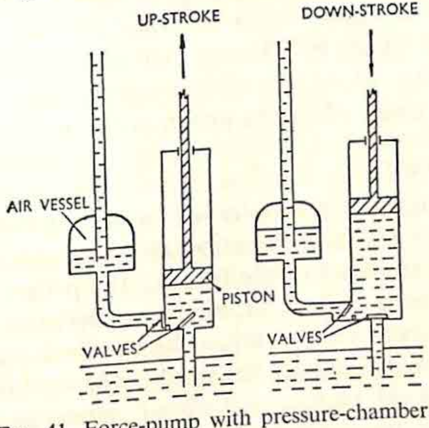


FIG. 41. Force-pump with pressure-chamber.

### THE FORCE-PUMP

To raise water to greater heights than this, a *force-pump* is often used. A force-pump (Fig. 41) is like a lift-pump except that there is a valve in the delivery-pipe at the lower end of the cylinder, and that the piston is solid. When the piston is pulled up, the valve in the delivery-pipe closes and water rises into the cylinder through the foot-valve, as in the lift-pump, owing to the pressure of the air outside. When the piston is pushed down, the foot-valve closes and the water is forced into the delivery-pipe, i.e. *the water is forced out on the down-stroke* of the piston*. Hence, the height to which the water will rise depends on the force with which the piston is forced downwards, and not on the air pressure. Some modern force-pumps, such as those used on fire-engines, will force water to a height of several hundred feet.

### AIR VESSELS ON FORCE-PUMPS

The ordinary force-pump delivers water only on the down-stroke of the piston and the flow of water stops during the up-stroke. For many purposes, e.g. in fire-engines, a steady stream of water is required. To produce a steady stream, an *air vessel* is fitted to the delivery-pipe of the force-pump, as shown in Fig. 41. During each down-stroke, some water is forced into the air-vessel, compressing the air inside it. During each up-stroke, this air expands and forces water along the delivery-pipe, thus maintaining* a steady flow of water while the piston is rising.

### THE BICYCLE PUMP

A bicycle pump is the simplest example of a *compression-pump*. The air can move in one direction only, because the cup-shaped leather washer attached to the head of the piston acts as a valve. When the handle is pulled out, air passes between the washer and the wall of the cylinder, but when the handle is pushed in, the air is compressed, and it presses the sides of the washer tightly against the walls of the cylinder so that no air can escape between them. (see Fig. 43). As the air inside the pump becomes more compressed, it forces open the valve in the tyre. This consists of a narrow metal tube, closed except for a small hole in the side (see Fig. 42). This hole is covered with a rubber tube that allows air to enter the tyre, but prevents it from escaping again. If a bicycle pump is fitted with a reversed valve and washer, it can be used as a simple air-pump, i.e. a 'suction-pump'.

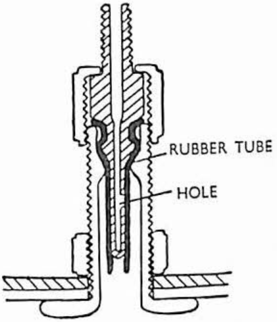


FIG. 42. Bicycle tyre valve.

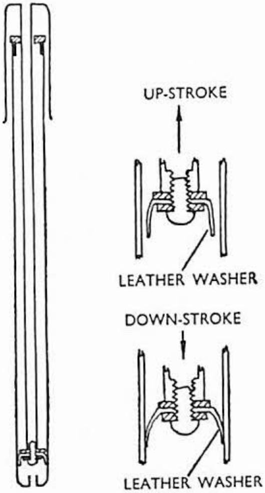


FIG. 43. Bicycle pump.

JET-PUMPS

When a fluid at a high pressure escapes through a small jet at a high speed, a region of low pressure is produced round the jet. This principle is the basis of several kinds of pumps used in everyday life. The laboratory *filter-pump*† shown in Fig. 44 is a useful type of air-pump. Water at a *high pressure* enters at the top of tube A. This tube gets narrower and narrower until it ends in a fine jet. As the water rushes out of this jet at a very *high speed*, there is a region of *low pressure* round the jet, and air from the space C is 'sucked in' and carried down the tube B. If the side-tube D is connected to a closed vessel, air can be drawn out of the vessel, but a water jet-pump will never give a perfect vacuum.

A similar jet-pump, using high-pressure *steam* instead of water, is used to reduce the air-pressure in the 'train-pipe' and brake-cylinders of the 'vacuum-brake' system on a railway train (see p. 89).

*Pressure-sprays** (e.g. fly-sprays, paint-sprays, and garden sprays) work on the same principle. As shown in Fig. 45, air escapes at a *high speed* from a small jet X, producing a *low pressure* round the jet. A small quantity of the liquid in Y is 'sucked up' the vertical tube Z and is then blown away as a fine spray of very tiny drops.

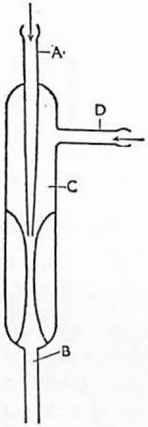


FIG. 44. Filter-pump.

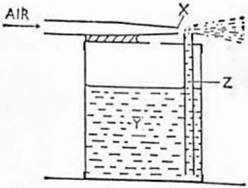


FIG. 45. Pressure-spray.

AUTOMATIC BRAKES ON RAILWAY TRAINS

Nowadays, most passenger trains are fitted with *automatic brakes* that can be applied to every wheel of the train. Both the driver and the guard can control these brakes, or, in case of accident, the brakes apply themselves automatically. These automatic brakes are of two main types: (i) *vacuum brakes*, and (ii) *pressure brakes* (or 'Westinghouse' brakes).

THE VACUUM AUTOMATIC BRAKE

A metal pipe, called the 'train pipe', runs from the engine to every carriage, where it is connected to a brake-cylinder fitted with a piston that works the brakes. A 'steam ejector'* on the engine, working on the same principle as a laboratory filter-pump, produces a very low pressure in the 'train pipe' and in the space *below* the piston, thus pulling the piston downwards and taking *off* the brakes (see Fig. 46). To apply the brakes, the driver shuts off the steam jet in the ejector and admits air into the 'train pipe'. The pressure of this air forces the piston *upwards* and thus applies the brakes. If there is an accident, and the 'train pipe' is broken at any point, air enters and the brakes are applied automatically to every wheel throughout the train.

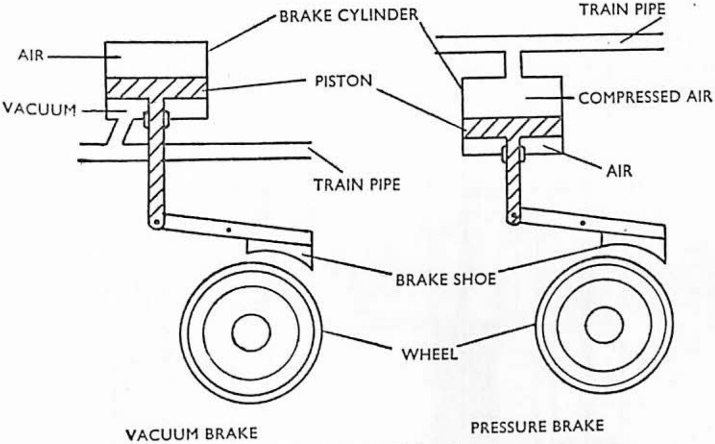


FIG. 46. Automatic brakes.

THE 'WESTINGHOUSE' AUTOMATIC BRAKE

This is very similar in its action to the vacuum brake but is worked by *compressed air* (see Fig. 46). When compressed air from the engine is passed into the 'train pipe' and the brake-cylinders, the piston is forced *downwards* and the brake is taken *off*. When the compressed air from the engine is allowed to escape, the air on the other side of the piston expands again and the piston is forced *upwards*, thus applying the brakes. As in the case of the vacuum brake, when the 'train pipe' is broken, all the brakes are applied automatically.

In the same way, railway signals are sometimes worked by compressed air, and when an accident damages the air-pipes, every signal is set automatically at '*danger*'.

### THE SIPHON

It is not always possible or convenient to lift a vessel of liquid in order to pour its contents into another vessel, and in such cases we often use a *siphon*, which makes use of air pressure to transfer* the liquid.

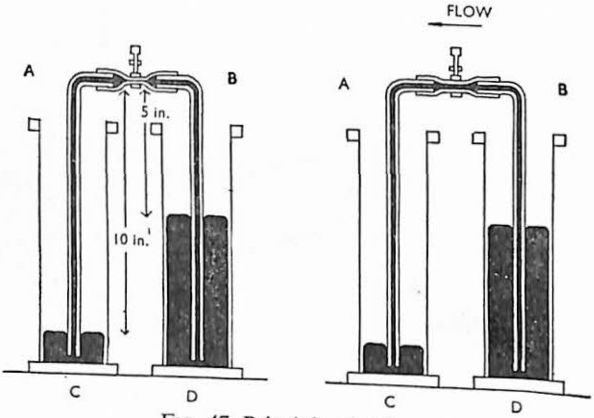


FIG. 47. Principle of siphon.

A siphon consists of a bent tube having one limb longer than the other. The shorter limb is dipped into the liquid and the tube is then filled with liquid by sucking at the open end of the siphon. The liquid then flows through the tube, and continues to flow as long as the open end of the siphon is below the level of the liquid inside the vessel.

This very simple device can be explained as follows: Imagine two tubes, A and B (see Fig. 47), filled with mercury and joined at their upper ends with rubber tubing closed by a screw-clip, and with their lower ends dipping into two cylinders C and D containing mercury, C being nearly empty and D nearly full.

When the pressure of the atmosphere is 30 inches of mercury, if the top of the tube A is 10 inches above the level of the mercury in C, the pressure at the top of the tube A can support (30—10) = 20 inches of mercury.

Similarly, if the top of the tube B is 5 inches above the surface of the mercury in cylinder D, the pressure at the top of tube B can support (30—5) = 25 inches of mercury.

If the screw-clip is now opened, as shown in Fig. 47, the pressure at the top of B being (25—20) = 5 inches greater than at the top of A, the liquid will flow from D to C, and will continue to flow as long as the level in D is higher than the level in C.

Notice that in a siphon the liquid is pushed from one place to another by a pressure that cannot exceed one atmosphere. Hence, in siphoning *water*, the height of the top of the siphon tube above the higher water surface cannot be more than 34 feet.

## PRESSURE IN LIQUIDS

### HOW IS PRESSURE TRANSMITTED THROUGH FLUIDS?

One of the most important properties of all *fluids* (liquids and gases) is that *fluids transmit* pressure equally in all directions*. For example, if we hold the opposite sides of a fairly soft bicycle tube and press with the right hand, we can feel this pressure transmitted through the air in the tyre to the left hand.

(i) We can illustrate this principle by using the apparatus shown in Fig. 48. The bulb of the glass vessel has several small holes, pointing in all directions, and the side-tube is fitted with a sliding piston. The apparatus is filled with water and the piston is then pushed in. Jets of water rush out from all the holes *with equal force*, showing that the pressure applied to the piston *is transmitted equally in all directions* by the enclosed liquid.

(ii) Another experiment to illustrate the same principle is shown in Fig. 49. The mouth of the short thistle-funnel A is closed by a thin sheet of rubber (part of a rubber balloon). This funnel A is attached by a short piece of thick rubber tube B to the glass tube C, which is connected in turn by the rubber tube D to an open-tube manometer E, containing coloured water. The tall glass jar is nearly filled with water and a rubber band is put round this jar an inch or two from the bottom. (*a*) The thistle-funnel is turned to face *downwards* and is pushed down into the water until its mouth is level with the rubber band. Owing to the *upward* pressure of the water on the rubber sheet, the coloured water rises in the outer limb of the manometer E and its level is marked by a rubber band F. (*b*) The experiment is repeated with the thistle-funnel turned to face *upwards* and pushed down in the water until its mouth is at the same depth as before. The coloured water in the outer limb of the manometer rises to the same height as before, showing that *at the same depth* the *downward* pressure is the same as the *upward*

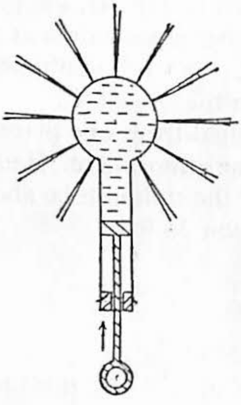


FIG. 48. Equal transmission of pressure in all directions.

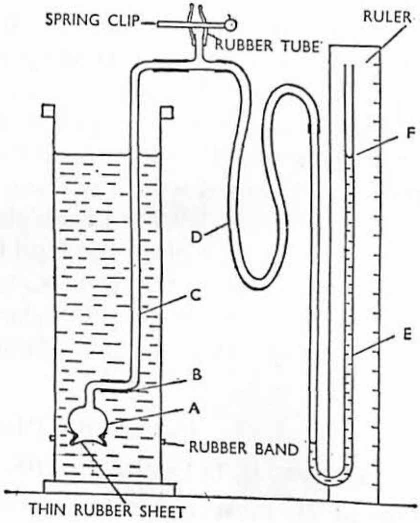


FIG. 49. Fluid pressure.

pressure. (*c*) The experiment is again repeated with the thistle-funnel turned to face *sideways* and pushed down in the water until the *centre* of the mouth of the funnel is at the same depth as before. The coloured water in the manometer rises to the same height as before, showing that the *sideways* pressure at this depth is the same as the *upward* and *downward* pressures, i.e. *the liquid presses equally in all directions.*

### HYDRAULIC MACHINES

This principle is made use of in *hydraulic* machinery* (that is, machinery driven by water power), e.g. the *hydraulic press* shown in Fig. 50. Hydraulic presses of this kind are used for pressing oil from oil-seeds, for packing raw wool and cotton for shipment, and for shaping metal, e.g. in making steel pressings for motor-car bodies. Hydraulic brakes on motor-cars also work in the same way. Fig. 51 explains the principle of such machines. If the diameter of the cylinder B is five times the diameter of A, the area of the cross-section ($\pi r^2$) of B is twenty-five times that of A. Hence, if a downward *pressure* of 1 lb. wt. per sq. in. is applied to the water in A, by means of a piston, this pressure P will be transmitted equally in all directions throughout the water in both A and B; and there will also be an upward *pressure* of 1 lb. wt. per sq. in. on

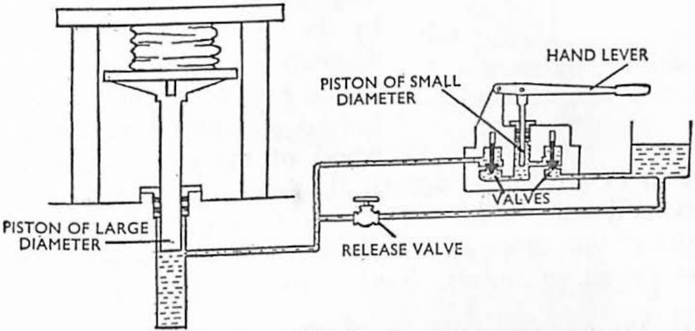


FIG. 50. Hydraulic press.

the piston in B. Thus the total upward *force* on the piston in B is twenty-five times the downward force applied to A. (Notice, however, that the piston in A must move downwards through 25 in. to raise the piston in B through 1 in., i.e. what is gained in *force* is lost in *distance*, or the product *force* × *distance* is the same in both A and B.) It is clear that by making A of very much smaller diameter than B, enormous forces can be produced. This principle is also used in hydraulic cranes* and hydraulic lifts.

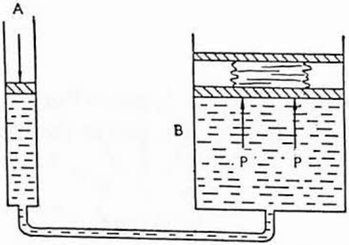


FIG. 51. Principle of hydraulic press.

In the hydraulic brake system of a motor-car, a small force is applied by the foot to a piston of small diameter. This pressure is transmitted equally through oil-pipes to pistons of larger diameter at each wheel of the car, so that all the brake-shoes are forced against the brake-drums with the same increased thrust.† (N.B.—The total force acting on a surface is called a *thrust*. Since *pressure* is the *thrust on unit area*, e.g. 14·7 lb. wt. per sq. in. for air, *thrust* = *pressure* × *area*.)

DEPTH AND PRESSURE

We have seen that the pressure of the atmosphere is greatest at sea-level and that it decreases with increasing altitude. The same thing applies to liquids: the deeper a diver goes down in the sea, the greater the water pressure becomes.

(i) The simple experiment shown in Fig. 52 illustrates this. A tall vessel has openings in its sides fitted with horizontal tubes of equal diameter (a tall tin bored with $\frac{1}{8}$-in. holes at 1-in. intervals will do equally well). When the vessel is filled with water, it shoots out of the bottom tube with much greater force than it does from the top tube, and the flow from the middle tube is greater than the one above but less than the one below.

(ii) The apparatus shown in Fig. 49 can also be used to compare pressures at different depths. Rubber bands are put round the jar at intervals of 5 cm. to mark depths below the surface. The thistle-funnel (without its rubber sheet) is turned mouth-downwards and pushed down in the water and clamped at a depth of 5 cm. The difference between the water-levels in the manometer E is then read off. The funnel is then pushed down to depths of 10 cm., 15 cm., 20 cm., and so on, measuring the pressure from the 'head of water' in the manometer in each case. Notice that, *in a liquid, the pressure is proportional to the depth below the surface*, i.e. at twice the depth the pressure is twice as great. Hence, as a diver comes up from the bottom of the sea, the pressure acting on him decreases *uniformly*. As we rise in the atmosphere, however, although the air pressure acting on us decreases, it does *not* decrease uniformly (see p. 73). This difference between liquids and gases is due to the fact that *gases are compressible* (so their density is changed by pressure) while *liquids are almost incompressible* (so their density remains almost unchanged by pressure).

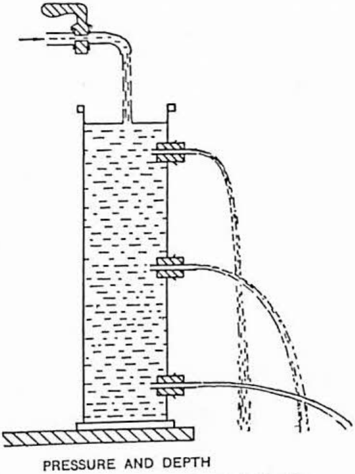


FIG. 52. Pressure and depth.

| DEPTH | PRESSURE (manometer reading in cm. of water) |
|---|---|
| cm. | cm. |
| cm. | cm. |
| cm. | cm. |
| cm. | cm. |
| cm. | cm. |

(iii) The last experiment is repeated after removing the thistle-funnel from the glass tube C, thus measuring the pressure on a smaller area. Notice that, with the open end of the tube at the same depths, the manometer readings are exactly the same as before (in Expt. ii above), showing that *the pressure inside a liquid depends only on the vertical depth below the surface* (and *not* on the area over which the pressure acts).

| DEPTH | PRESSURE (manometer reading in cm. of water) |
|---|---|
| cm. | cm. |
| cm. | cm. |
| cm. | cm. |
| cm. | cm. |
| cm. | cm. |

(iv) The apparatus in Fig. 53 shows this also. The dotted line marks the point in each tube at the same vertical depth below the water-surface. If the pressure at any two of these points were not the same, water would flow from one tube to the other and their surfaces would no longer be at the same horizontal level. So this experiment also shows that the pressure at these points depends on their vertical depth and *not on the shape of the tubes*. There is clearly a different *weight* of water above the dotted line in the different tubes, but this makes no difference to the *pressure* at the same depth below each surface.

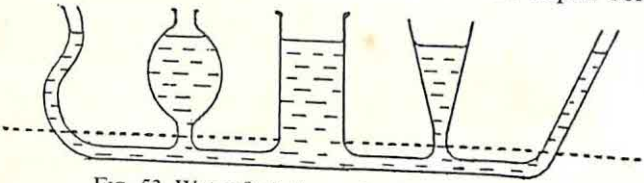


FIG. 53. Water finds it own level in wide tubes.

PASCAL'S EXPERIMENT

The following experiment (shown in Fig. 54) was first carried out by the French scientist Pascal (1623–62). (Pascal also discovered the principle that liquids transmit pressure equally in all directions and he was also the first man to measure altitude from barometer readings.)

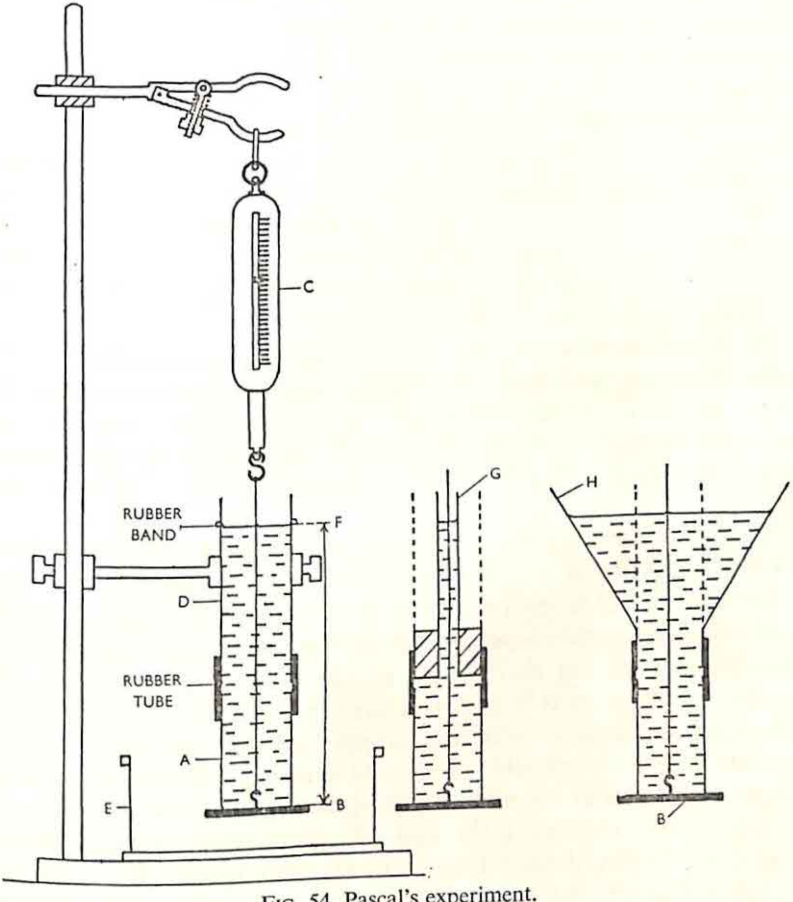


Fig. 54. Pascal's experiment.

(*a*) The short brass tube A (of at least 1 in. diameter) is closed at the bottom with a flat brass disc B, which is hung by a thread from the spring balance C. A glass tube D, of the same diameter, is joined to A by a piece of rubber tube and *clamped* in a vertical position beneath the spring balance. The weight of the brass disc is first noted (........gm.) and the spring balance is raised so that the pull on the thread is 100 gm. Water is then poured into the tube until the brass disc B is displaced by the down-thrust of the water, which then runs out. This water is caught in the vessel E and its volume is measured (........c.cm. = ........gm.). After repeating the experiment several times, it is found that the weight of this vertical column of water is always the same as the reading of the spring balance *minus* the weight of the brass disc B (100—........ = ........gm.). A rubber band F is put round the glass tube D to mark the level at which the down-thrust of the water is equal to the upward pull of the spring balance. The height of this column of water (BF) is measured (........cm.).

(*b*) The glass tube D is now removed and replaced by the narrow tube G, which is clamped in position and marked with a rubber band at the same vertical height as in (*a*). The experiment is repeated, and it is found that water runs out of the apparatus when *the vertical height of the column of water is the same* as in (*a*).

(*c*) The experiment is again repeated with the funnel H attached to the brass tube A, and it is again found that the water runs out when *the vertical height of the column of water is the same* as in (*a*) and (*b*). Hence, *the shape and size of the tubes* D, G, *and* H *make no difference to the down-thrust of the water*, and although the *weights* of water used in Experiments (*a*), (*b*), and (*c*) are different, *the down-thrust on the disc* B *is always equal to the weight of the column of liquid vertically above it*, as shown by the dotted lines in diagrams G and H, i.e. the weight of the water in (*a*).

(*d*) If Experiments (*a*), (*b*), and (*c*) are repeated with a different liquid of smaller density (e.g. alcohol), it is found that a longer column of liquid can be supported by the same pull of the spring balance, and that the vertical height of this longer column of alcohol is again the same in all three vessels D, G, and H. If the heights of the water columns in Experiments (*a*), (*b*), and (*c*) are compared with those of the alcohol columns, it is found that *these heights are proportional to the densities of the two liquids.*

### PASCAL'S LAW

Experiments like these led Pascal to state that *the pressure on a surface under a liquid in an open vessel is always equal to the vertical height of the column of liquid multiplied by the weight of unit volume of the liquid*, no matter what the shape or size of the vessel may be.

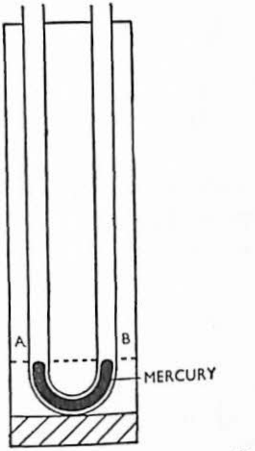


FIG. 55. Balancing columns (i).

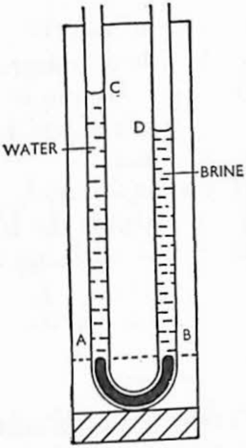


FIG. 56. Balancing columns (ii).

### BALANCING COLUMNS

(i) Pour some mercury into a glass U-tube fixed on a board as shown in Fig. 55.

What is the pressure at A?. . . . . . . . . . . . . . . . . . . . . . . . . . . . .

What is the pressure at B?. . . . . . . . . . . . . . . . . . . . . . . . . . . . .

Draw a horizontal line on the board to mark the level AB.

(ii) Pour water into one limb of the U-tube, and saturated salt solution (brine) of known specific gravity into the other limb, until the mercury surfaces stand at the same level as before, as shown in Fig. 56.

What is the pressure at C?..............................

What is the pressure at D?..............................

But the pressures at A and B are also the same (see Expt. i); hence we have a column of water balanced by a column of brine. Measure the height of these columns.

| HEIGHT OF WATER COLUMN ($L$) | HEIGHT OF BRINE COLUMN ($l$) | $L \div l$ |
|---|---|---|
| cm. | cm. | |

Compare your result ($L \div l$) with the specific gravity of the brine as shown by a hydrometer..............................

Hence we can use this method of balancing columns to find the specific gravity of a liquid, balancing a column of the liquid against a column of water.

(iii) If the liquid does not mix with water, the mercury is unnecessary. Repeat the last experiment, balancing a column of kerosene against a column of water as shown in Fig. 57.

| HEIGHT OF WATER COLUMN ($L$) | HEIGHT OF KEROSENE COLUMN ($l$) | $L \div l =$ S.G. |
|---|---|---|
| cm. | cm. | |

(iv) Repeat the experiment with a U-tube whose limbs are of different diameter, as shown in Fig. 58.

| HEIGHT OF WATER COLUMN ($L$) | HEIGHT OF KEROSENE COLUMN ($l$) | $L \div l =$ S.G. |
|---|---|---|
| cm. | cm. | |

If your values for the specific gravity of kerosene are the same in Experiments (iii) and (iv), it shows that the diameters of the tubes make no difference to the heights of the columns of water and kerosene that balance each other. This is because we are balancing *pressures* and *not* weights. By Pascal's Law, the *pressure* at A, due to the column of water, is the height AC times the weight of unit volume of water ($x$); while the pressure at B, due

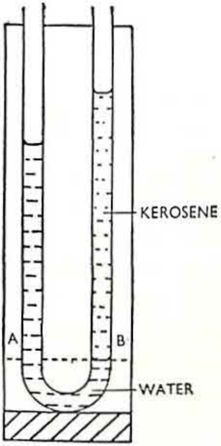


FIG. 57. Balancing columns (iii).

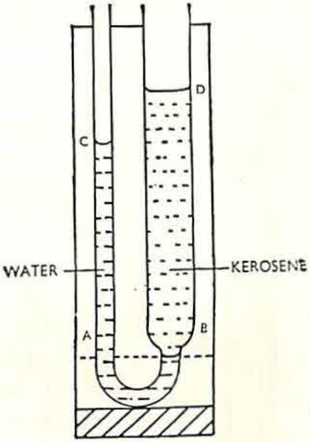


FIG. 58. U-tube with limbs of different diameter (iv).

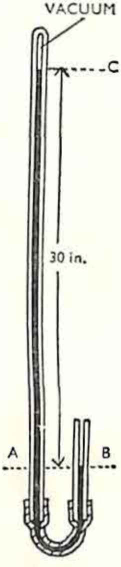


FIG. 59. Simple barometer.

to the column of kerosene, is the height BD times the weight of unit volume of kerosene ($y$).

Hence $$\mathrm{BD}\times y = \mathrm{AC}\times x$$

therefore $$\frac{y}{x} = \frac{\mathrm{AC}}{\mathrm{BD}}$$

$$\text{But, S.G. of kerosene} = \frac{\text{weight of unit volume of kerosene}}{\text{weight of unit volume of water}}$$

$$= \frac{\text{height of column of water}}{\text{height of column of kerosene}}$$

Notice that a mercury barometer uses the same principle of balancing columns. In Fig. 59 the pressures at A and B are the same; hence the column of mercury (AC) in the closed tube of the barometer balances the column of air pressing on the mercury surface B in the open limb. These experiments make it clear why barometers with tubes of different diameter all give the same reading under the same conditions.

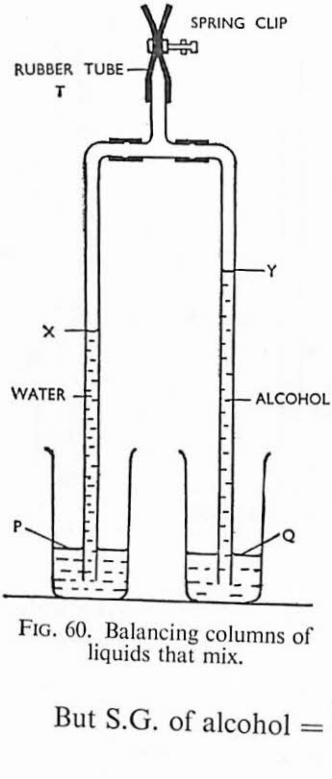


FIG. 60. Balancing columns of liquids that mix.

(v) With liquids that mix, it is easier to use an inverted U-tube than to use mercury as in Experiment (ii). Fit up the apparatus shown in Fig. 60 with one limb dipping in a beaker of water and the other in a beaker of alcohol (methylated spirit). 'Suck up' the liquids as shown in the diagram, and close the rubber tube T with a clip. Notice that the pressure on the surfaces X and Y is the same, and that the pressures on the surfaces P and Q are each 'one atmosphere'. Hence the pressures exerted by the two columns of liquid are the same, i.e. *height of water × the weight of unit volume of water = height of alcohol × the weight of unit volume of alcohol.*

$$\text{But S.G. of alcohol} = \frac{\text{weight per unit volume of alcohol}}{\text{weight per unit volume of water}}$$

$$= \frac{\text{height of \textit{water} column}}{\text{height of \textit{alcohol} column}} = \underline{\qquad\qquad}$$

Therefore, S.G. of alcohol = . . . . . . .

Notice that by using the *principle of balancing columns* we can find specific gravities of liquids without using a balance.

Learning Exercises on Chapter IV will be found on pp. 37–52 of *General Science Workbook I.*

## CHAPTER V

# PLANT LIFE

### HOW DO PLANTS GET THEIR FOOD?

It is easy to see how the most familiar *animals* feed by taking in solid food through their mouth. But plants have no mouth and therefore cannot take in food in the solid state, but only in *fluid* form as liquids and gases. Everyone knows that plants take in water from the soil, but it was not until the eighteenth century that men discovered how green leaves manufacture food for the plant. In 1771 Joseph Priestley (whom you will remember as the discoverer of oxygen) showed that *green leaves, in sunlight, give out oxygen if they are supplied with carbon dioxide.*

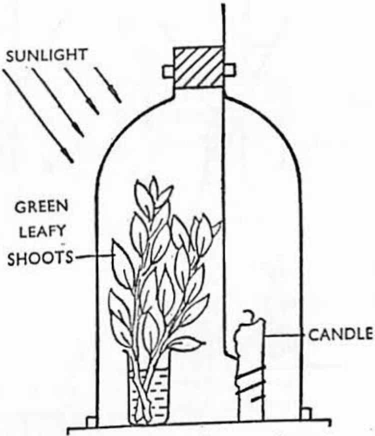


FIG. 61. Priestley's experiment.

Priestley's historic experiment is easily repeated. A lighted candle is placed in a closed glass jar containing some young green leaves, as shown in Fig. 61. After a short time, the candle flame goes out because most of the oxygen in the jar has been used up, and carbon dioxide is formed in its place. If the jar is then kept in bright sunlight for a few hours, it is found that the candle can be lighted once more, and that it continues to burn for the same length of time as before, showing that the green leaves must have replaced the oxygen used up by the burning candle.

When the experiment is repeated by allowing the candle to burn out and then keeping the jar *in the dark* for a few hours, the candle will not continue burning when lighted again, showing that in the dark the green leaves do *not* give out oxygen.

The same thing can be shown in a very striking way by using green water plants. Three large flasks are fitted up as shown in

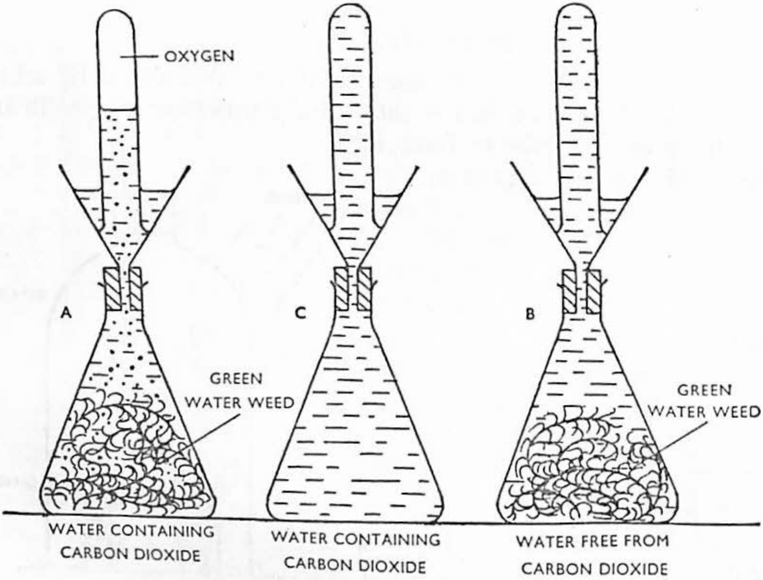

OXYGEN
A
C
B
GREEN WATER WEED
GREEN WATER WEED
WATER CONTAINING CARBON DIOXIDE
WATER CONTAINING CARBON DIOXIDE
WATER FREE FROM CARBON DIOXIDE

FIG. 62. Oxygen set free by green leaves in sunlight.

Fig. 62. Flasks A and C are completely filled with water through which carbon dioxide has been bubbled for some time, i.e. with a dilute solution of carbon dioxide. Flask B is completely filled with water that has been boiled to remove any dissolved carbon dioxide and then allowed to cool: that is, with 'carbon-dioxide-free water'. Some green water-weed is placed in flasks A and B, and all three flasks are then put in bright sunlight with a test-tube of water inverted in each funnel at the mouth of the flask. In a short time, bubbles of gas are formed on the leaves in flask A,

and in time these bubbles rise and collect in the test-tube. When sufficient gas has collected, the test-tube is removed, its mouth closed with the thumb, and the gas is tested with a red-hot wooden splinter. The splinter bursts into flame, showing that the gas is mainly oxygen. In flask B, where the water contains no carbon dioxide, no oxygen is given off. In flask C, where the water contains carbon dioxide but no water-weed, no oxygen is given off. *Hence, green plants, in sunlight, give out oxygen if they are supplied with carbon dioxide.*

In Priestley's bell-jar experiment and also in the water-weed experiment, although it seems probable (and actually it is certain) that carbon dioxide is taken up by green leaves at the same time as oxygen is set free, you will notice that we have as yet no *proof* of this second fact. All that we have *proved* is that when carbon dioxide is present, green leaves can give out oxygen in the light. The experiment which *proves* that carbon dioxide is actually absorbed is too difficult to do at this elementary stage, but it is simple in principle. A leaf is shut up in a vessel containing *a known amount of carbon dioxide*, and is then exposed to light for some hours. Chemical analysis of the gas in the vessel shows that the carbon dioxide has decreased in amount while the amount of oxygen has increased.

## HOW DO GREEN LEAVES MAKE FOOD MATERIALS?

The carbon dioxide that gets into the leaves comes into contact with the water present inside the leaves and with the 'leaf green'. When light falls on the leaf, chemical reactions take place, and the carbon, hydrogen, and oxygen from the carbon dioxide and water are recombined into complex compounds called *carbohydrates*, and some oxygen is liberated. Carbohydrates are compounds of carbon, hydrogen, and oxygen, in which the hydrogen and oxygen are present in the same proportions as in water. Familiar examples are sugar, starch, and filter paper (*cellulose*).[†] We believe that a simple sugar called *glucose*[†] is the first of these

Govt. of West Bengal

carbohydrates to be formed in leaves, but in many plants it is rapidly changed into the more complex carbohydrate, *starch*, which is insoluble in water. We shall learn more about carbohydrates in Book Four.

It is very easy to show when starch is present in a leaf because there is a very delicate, though simple, test for it—*starch gives a deep blue colour with iodine*. Hence, in most of our experiments with green leaves we shall test for starch and not for sugar, because the test for sugar is too complicated for this stage of our Science Course. You should remember, however, that *sugar is probably the first carbohydrate formed in green leaves*, and that it may be changed into starch.

## HOW TO TEST FOR STARCH

Take a *little* starch† and shake it up with some water in a test-tube. Boil the suspension and then pour it into a beaker of cold water so as to get a very dilute solution of starch. Add a few drops of *iodine* solution.[1] A deep *blue* colour is formed that is a very delicate test for starch.

## HOW TO TEST FOR STARCH IN GREEN LEAVES

Take a bright green leaf (e.g. of Balsam, Cassava, Cow-pea, or Sword-bean) which has been growing in sunlight for some hours, and heat it in *boiling* water for five minutes, so as to kill the leaf. Then put the boiled leaf in some *alcohol* (methylated spirit) in a test-tube and warm the alcohol by putting the test-tube in hot water (*not* over a flame). The alcohol dissolves out the green colouring matter ('*leaf-green*') from the leaf, which becomes almost white and transparent. Wash the decolorized leaf in boiling water for a few minutes, to soften it, and then put it into some iodine solution. The leaf turns a deep blue colour, or even black, showing that it contains starch.

---

[1] Iodine dissolves readily in water containing some potassium iodide. Do not use an alcoholic solution (or tincture†) of iodine.

### HOW TO SHOW THAT CARBOHYDRATES ARE FORMED ONLY IN THE GREEN PARTS OF PLANTS

Some plants have leaves with colourless or yellow patches containing no leaf-green (e.g. some Caladiums† and some kinds of Cassava). If the last experiment is repeated with one of these green-and-white leaves, which has had a few hours' exposure to sunlight, it is found after killing and decolorizing the leaf that *only those parts that were green in the original leaf turn blue with iodine* (see Fig. 63). Hence, *starch is only formed where leaf-green is present*, that is, *the presence of leaf-green is necessary for the formation of carbohydrates.* (N.B.—Do not use a leaf with red patches, because a red leaf usually has leaf-green beneath the red colouring matter, and can therefore make carbohydrates even in the red patches.)

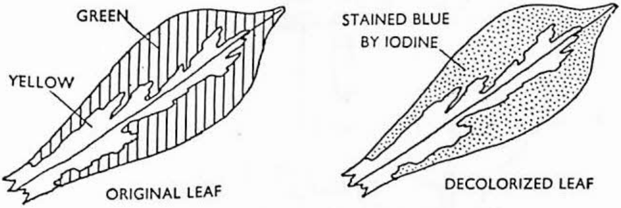


FIG. 63. Starch formed in green parts only.

### HOW TO SHOW THAT SUNLIGHT IS NECESSARY FOR THE FORMATION OF CARBOHYDRATES

Use young leaves of Balsam, or Cow-pea, or Sword-bean that are still attached to the plant, and partly cover them with folded strips of stiff brown or black paper. If desired, simple patterns (letters, etc.) may be cut out of one half (that which will lie on the upper leaf surface). Double the strip over the leaf blade and keep it in place with paper clips (see Fig. 64). The shade may be fixed at any time of the day, but it must be left on the leaf overnight and then for the greater part of the next day, which should preferably be sunny. (During the night all the starch originally present is removed.) After several hours' exposure to sunlight on the second day, remove the leaf and heat it in boiling water for five minutes, decolorize with alcohol, soften, and test for starch with iodine.

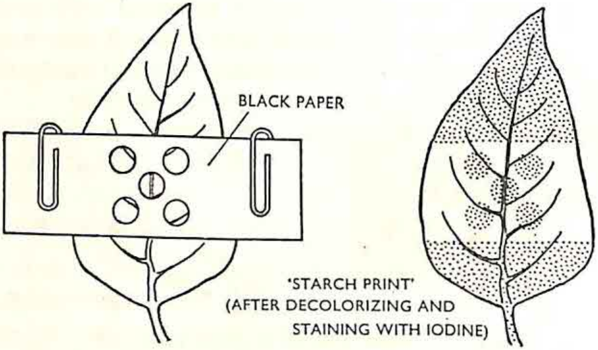


FIG. 64. Starch prints.

This experiment should show you that *carbohydrates are only formed in sunlight*—not in the dark.

HOW TO SHOW THAT CARBON DIOXIDE IS NECESSARY FOR THE FORMATION OF CARBOHYDRATES

Use a plant (e.g. Cow-pea or Sword-bean) that has been kept in the dark for about twelve hours (or set up the experiment overnight) so as to make sure that the leaves are free from starch at the beginning of the experiment. Arrange one of the leaves as shown in Fig. 65, so that one leaflet is inside a glass vessel containing a little sodium hydroxide solution, i.e. the leaf is in air that is free from carbon dioxide. After the plant has been exposed to sunlight for a few hours, remove the leaflet from inside the jar, together with another neighbouring leaflet that has been in the outside air, i.e. in air that contains 0·03 per cent. of carbon dioxide.

Boil, decolorize, and test both leaves for starch with iodine. Starch is only present in the leaflet that was outside the jar: the other green leaflet, which received sunlight but no carbon dioxide, has no starch. Hence, *carbon dioxide is necessary for the formation of carbohydrates.*

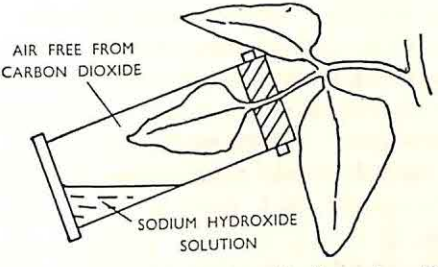


FIG. 65. Experiment to show necessity for carbon dioxide.

PHOTO-SYNTHESIS

The last three experiments show that *some of the conditions necessary for the formation of carbohydrates by plants* are:

(i) *Leaf-green must be present,*
(ii) *The leaves must receive light of sufficient brightness.*
(iii) *Carbon dioxide must be present.*

Further conditions (which we have not yet demonstrated experimentally) are:

(iv) *The temperature must be between certain limits.*
(v) *There must be a supply of certain mineral salts.*

In this process, therefore, *green leaves, in sunlight, use carbon dioxide (from the air) and water (from the soil) to build up carbohydrates; during this process they give off oxygen.* This process is sometimes called 'carbon-assimilation'* because this is how the plant gets the carbon that is such an important constituent of its food material. The process is also known as *photo-synthesis*† because the plant builds up carbohydrates under the influence of light: in fact, this is much the better name of the two and we shall use the word *photo-synthesis* throughout this Science Course.

Sunlight is necessary to supply the *energy* required to build up the complex carbohydrates from the simpler substances *carbon dioxide* and *water.* When sugar, starch, wood, or any other plant material burns, it combines with oxygen from the air, forming carbon dioxide and steam (or water vapour) and giving out *heat*, which is a form of energy. For example, if we burn wood under a boiler we can change water into steam, which possesses *more energy* than the water from which it was formed. This steam can be made to do *work* in driving a steam engine before it condenses to liquid water again. *Energy* means '*ability to do work*', and anything that can 'do work' possesses energy. Heat, electricity, light, sound, movement, and chemical energy are the commonest forms of energy.

Sugar, starch, wood, and other plant materials are therefore changed into carbon dioxide and water vapour, *and energy is set free* when they are burnt in oxygen (or when they are *oxidized*). For example:

$$\text{(i) SUGAR} + \text{OXYGEN} \xrightarrow{\textit{burns}} \text{CARBON DIOXIDE} + \text{WATER} + \text{ENERGY } (\textit{heat and light})$$

You will remember that a carbon compound is oxidized in living things during *respiration*. It is known (although we cannot prove it experimentally at this stage) that this compound is *sugar*. Hence equation (i) above is also the equation for respiration if we modify it slightly, as follows:

$$\text{(ii) SUGAR} + \text{OXYGEN} \xrightarrow{\textit{respired}} \text{CARBON DIOXIDE} + \text{WATER} + \text{ENERGY } (\textit{heat, growth, movement})$$

*Photo-synthesis* is the converse change. The leaf-green absorbs that part of sunlight which supplies the necessary energy, thus:

$$\text{(iii) CARBON DIOXIDE} + \text{WATER} + \underset{\textit{light}}{\text{ENERGY}} \longrightarrow \text{SUGAR} + \text{OXYGEN}$$

The two last equations represent the two most important processes in the world of living things: (iii) *photo-synthesis, the building-up of carbohydrates by green plants in sunlight*, and (ii) *respiration,* *the oxidation of these compounds by living things.* In both processes, energy changes take place.

## WHAT IS THE EVERYDAY IMPORTANCE OF PHOTO-SYNTHESIS?

From our point of view, photo-synthesis is perhaps the most important process taking place on the Earth, for the food of all animals is obtained from green plants, either directly or indirectly. It is true that some animals feed mainly on other animals, but the victims got their food from plants in the first place. During photo-synthesis, green plants change the energy of sunlight into *chemical energy*, stored up in plant material, mainly in the form of carbohydrates.

Animals differ from plants in being unable to transform* light energy in this way. Animals and plants are alike, however, in requiring energy during their growth and development. They both make use of the energy stored up in carbohydrates by green plants. *They transform this chemical energy into useful forms during the process of respiration.*

The 'highest' animal—Man—makes use of this chemical energy stored up by plants in another way, apart from feeding and respiration. Much of the world's work is now done by machines, and the energy required to drive these machines is mostly obtained by burning *coal*. But coal is the remains of forests that grew many hundreds of thousands of years ago, and the trees in these forests absorbed the *energy* of sunlight as they grew. We can say, in fact, that our railway engines are driven by 'bottled sunshine'—energy stored up in the coal for sometimes over a million years. Petroleum, also, is believed to be a direct or indirect product of green plants. We see, therefore, that *our food supply and most of the energy used to drive our machines depend on photo-synthesis.*

## WHAT HAPPENS TO THE CARBOHYDRATES FORMED IN GREEN LEAVES?

If green leaves are kept in the dark they lose any starch they may contain. We have already used our knowledge of this in experiments demonstrating photo-synthesis.

Pick several leaves of a rooted plant (e.g. Balsam or Cow-pea) at the end of a sunny morning and show by the iodine test that they are rich in starch. These leaves are *assumed to be typical* of similar leaves on the same plant. Now darken the plant with a black box for 12–15 hours and then pick some similar leaves and again test for starch. Notice that most or all of the starch has disappeared during the period of darkness.

Leaves are normally darkened each night for several hours and by dawn* they usually contain no starch. This is because the insoluble starch is changed back into soluble sugar, and this is removed through the leaf veins to other parts of the plants.

If, in the experiment described above, one of the main veins of a leaf is cut across, the sugar is unable to get away and in the part of the leaf served by that vein the starch remains unchanged, even in the dark.

The removal of carbohydrates from the leaf each night (actually some also gets away during the day) means that the leaf does not become blocked, as it were, with the products of photo-synthesis. But, what is more important, the sugar removed goes to supply other non-green parts of the plant with food. Some of this food material is used for *growth*, for building up parts of the plant, and some of it is used for *respiration*; for plants, like animals, obtain the *energy* required for growth and movement by *oxidizing sugar*. Fortunately for animals, most plants manufacture more food than they need for their own use, and they store up the excess in various parts of the plant. For example, rice stores starch in its seeds, sugar-cane stores sugar in its stem, the sweet potato stores both starch and sugar in its underground stems, the beetroot stores sugar in its swollen tap-root, the coconut palm stores oil in its fruit, and all of these *reserve food materials* are of great importance to Man. In fact, '*Plants are the savers, animals the spenders*'.

HOW DOES CARBON DIOXIDE ENTER THE LEAVES?

The green leaf of a land plant is covered by a skin that has an outer layer (or *cuticle*†) of a fatty, almost water-proof and gas-proof substance. This leaf-skin, however, has a large number of tiny holes in it, called *stomates*,† and although these openings are extremely small (less than 0·001 inch in diameter) it is through them that all the carbon dioxide passes from the air into the interior* of the leaf. The stomates can open and close under different conditions. *They are usually open in daylight*, if the leaf is well supplied with water. There is no actual breathing mechanism,* i.e. air is not 'sucked' into the leaf as it is into our lungs; instead, the carbon dioxide molecules *diffuse* into the interior because they are present there in smaller concentration than in the outside air (see p. 50).

### HOW TO SHOW THE PRESENCE OF STOMATES IN THE LEAF-SKIN

We can show the presence of stomates by the following simple experiments:

(i) Put a green leaf into hot water (nearly boiling). Bubbles of air are formed on the surface of the leaf wherever there is a stomate, because the heat makes the air inside the leaf expand and escape through the stomates. It is usually found that more bubbles are formed on the *under* side of the leaf than on the upper surface, showing that *most of the stomates are in the under surface* (in dicotyledon leaves, at any rate).

(ii) Another way of showing the presence of stomates is to place a green leaf inside a jar filled with water, with its leaf-stalk passing through a hole in the cork, as shown in Fig. 66. If the jar is now connected to a suction-pump (or if the leaf-stalk is connected to a bicycle pump) bubbles of air rise from the surface of the leaf, showing that the leaf-skin has a very large number of small pores through which air can pass. This experiment also shows that air can enter the cut end of the leaf-stalk and reach every part of the leaf. (In order to get an air-tight fit round the leaf-stalk, take a cork borer of larger diameter than the leaf-stalk and first pass it through the hole in the rubber cork. Then put the leaf-stalk in the open end of the cork borer, pull out the cork borer and leave the undamaged leaf-stalk firmly fixed in the cork.)

Stomates are too small to be seen with the help of an ordinary hand lens, but if a microscope or micro-projector is available you can actually see the stomates in a piece of leaf-skin. (A piece of transparent skin from a Crinum leaf or from the under-side of an Allamanda† leaf is suitable for this.) Under the microscope, the leaf-skin is seen to be built up of a large number of *cells*.† Most of these cells fit closely together (in Crinum—a monocotyledon—they look like bricks in a wall, and in Allamanda—a dicotyledon—they look like the pieces of a jigsaw* puzzle), but here and there are *stomates*, each with a small opening enclosed by two bean-shaped cells called the *guard-cells*. These guard-cells control the size of the stomate opening (see Fig. 67).

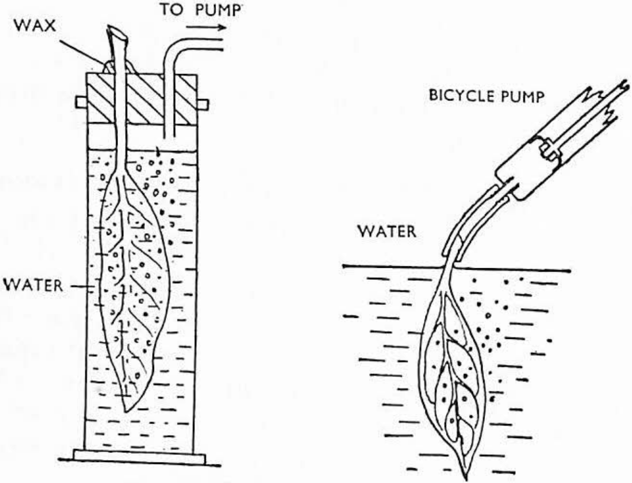


FIG. 66. Forcing air through stomates.

As this is the first time that you have seen an actual cell we must learn something about this very important structural unit. *Cells are the units of which all living things are built*. The simplest plants and animals consist of one single cell, but the more familiar plants and animals are built up of millions of these tiny living units. Each plant cell is a tiny box, enclosed by a *cell-wall* composed of the carbohydrate *cellulose.* If the cell is living it is lined with a colourless jelly-like substance called *protoplasm.*† We shall have to learn more about this very important substance later because *protoplasm is the actual living material in all living things.* Except in very young plant cells, the protoplasm does not completely fill the cell but forms a thin layer, lining the cell-wall. The space inside is filled with *cell-sap*, a watery solution of sugar and mineral salts. A specially dense part of the protoplasm is called the *nucleus* † (see Fig. 68).

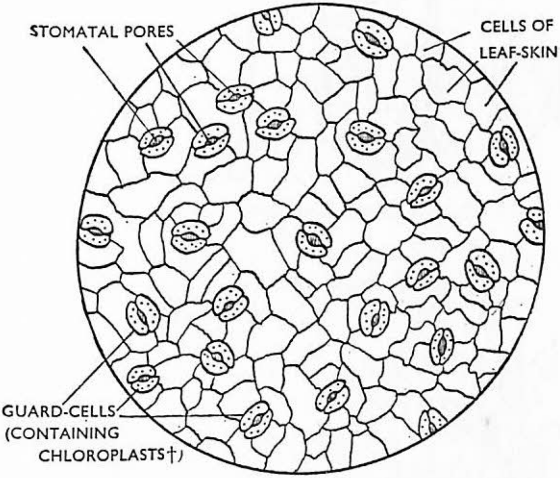
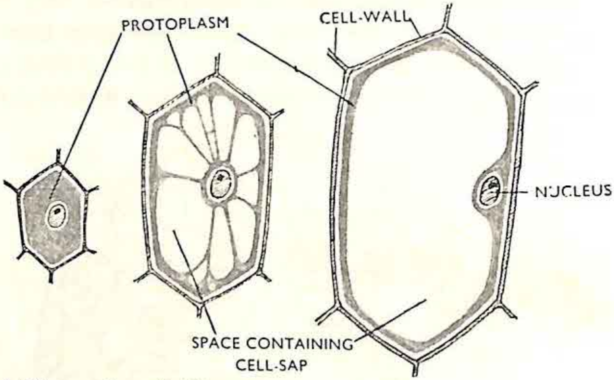


FIG. 67. Leaf-skin with stomates (highly magnified).

HOW DOES WATER GET TO THE LEAVES?

The element carbon is a most important part of the carbohydrate foods, for carbon is as exceptional among chemical elements as water is among chemical compounds. But do not forget that hydrogen and oxygen are also present in these foods, and that these elements come from the water in the leaf. This water comes from the soil, and we must now learn something about the passage of water from soil to leaf.



(*a*) Young cell. (*b*) Older cell. (*c*) Still older cell.

FIG. 68. Plant cells (highly magnified).

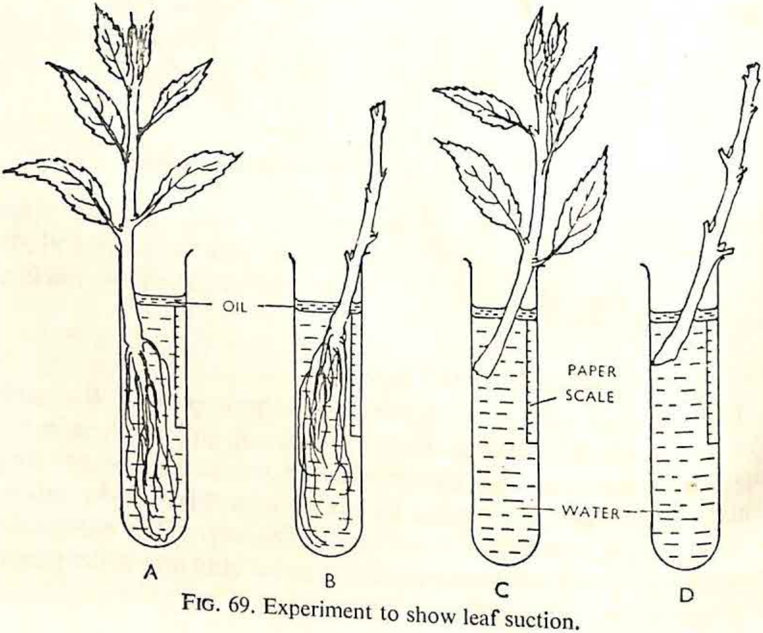


FIG. 69. Experiment to show leaf suction.

In Book One, Chap. IV, we learnt that water containing dissolved mineral salts is absorbed by the root-hairs growing just behind the growing *root tip* and that this water is passed on to the stem of the plant. From here it is raised mainly by *leaf suction*, as shown by the following experiments:

Using a set of four similar young Balsam plants, or any other plant with fairly broad flat leaves and a long stem, set up the experiment illustrated in Fig. 69. In tubes A and B the plants are placed with their roots (carefully dug up and washed) in water. In B the leaves on the shoot are cut off. Tubes C and D contain cut shoots only, C with, and D without, the leaves attached. Place the four tubes in a stand near an open window and mark the height of the water in all the tubes. After 24 or 48 hours mark the level again and explain the result. (What is the oil for?)

Experiments of this kind show that roots, or cut shoots, can take up considerable quantities of water, but *only when leaves are attached to the shoot*.

It seems that the leaves have a 'thirst' for water and suck it from the stem; the stem in turn sucks it from the roots and the roots absorb water from the soil, or (as in the above experiment) from the vessel in which they are standing. The way in which this leaf suction is transmitted downwards is too complicated for us to explain at present.

In some cases, e.g. Balsam, water can be absorbed by the root and actually forced out of the cut stem from which all leaves *have been removed*. But as it is doubtful whether this so-called 'root pressure' is a very widespread or important process in the life of all plants, we shall not deal with it here in detail. Water is, for the most part and at most seasons, sucked up by the leaves, far more than it is pushed up by the roots.

## HOW TO SHOW THE PATH OF WATER THROUGH THE PLANT

If a young, leafy, non-woody plant, e.g. Balsam, is placed with its roots in a dilute solution of red ink for several hours, the red colour appears in the flowers and in the veins of the leaves. If thin slices are cut from across the root and stem and examined with a lens, we can see that the coloured water has travelled along definite paths. In the root, the coloured liquid passes along a *central cylinder*, while in the stem it passes through a number of stringy fibres arranged in a ring near the outside of the stem. These coloured parts mark the position of the narrow tubes that carry water from the root, up the stem, to the leaves. A large number of these 'conducting-tubes' are grouped together to form fibrous bundles (called *vascular†-bundles* or 'conducting-bundles'). We shall see later that each vascular bundle consists of two kinds of tubes or *vessels*, (*a*) *wood*-vessels,† which carry water and dissolved inorganic salts to all parts of the plant, and (*b*) *bast*-vessels,† which carry manufactured organic food from the leaves to all parts of the plant. These vascular bundles are continuous from root-tip to leaf-tip throughout the plant.

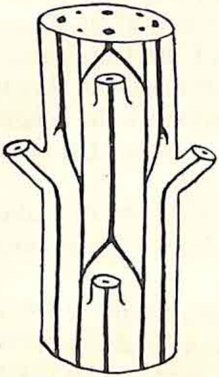
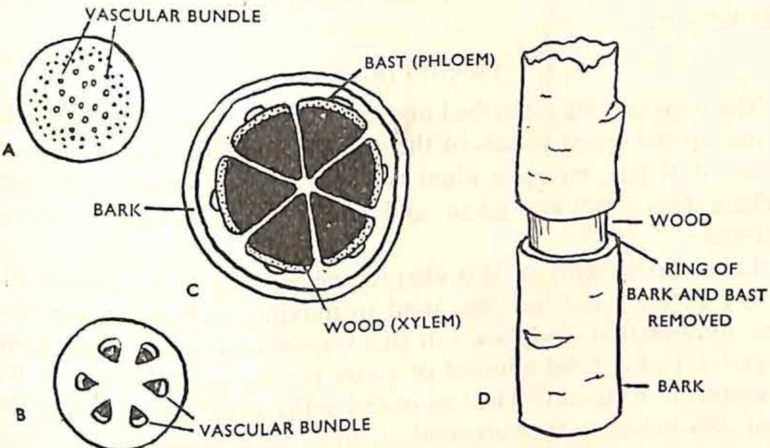


FIG. 70. Vascular bundles in a stem.

The existence of these bundles in the stem is very clearly shown if we dip a cut leafy stem of a Balsam plant into a deep blue watery solution of methylene blue.† The water and the deep blue dye enter the cut surfaces of the bundles more readily than they would get into them through the root, and the dye may be seen passing quite quickly up the bundles of the stem (which in this plant is almost transparent). In time, and travelling always in the vascular bundles, the dye reaches the leaves (and the flowers if any are present). Notice that the 'veins' of the leaves are the slightly thicker parts of the leaves through which the vascular bundles run. When the dye has reached the leaves, cut the stem across, in two or three directions, and notice the arrangement of these bundles. Compare it with that shown in Fig. 70.

In many non-woody net-veined plants (e.g. Balsam) the bundles are arranged to form a cylinder (see Fig. 71 B); in grass-like, parallel-veined plants (e.g. sugar-cane and maize) they are more numerous and are scattered throughout the stem (see Fig. 71 A). But in woody branches and trunks of net-veined trees the water is no longer carried in separate bundles. A cross-section of such a brown woody stem (e.g. Hibiscus)† shows a soft white *pith*† in the centre, then a layer of *wood* surrounded by a thin layer of *bast* and *bark*† (see Fig. 71 C). It is in the *wood* of such stems that the water travels.



A = Cross-section of a maize stem (monocotyledon).
B = Cross-section of a non-woody stem (dicotyledon).
C = Cross-section of a young woody stem (dicotyledon).
D = Part of a ringed woody shoot (dicotyledon).

FIG. 71. Stem structure.

Stand a leafy, *woody* stem in water coloured with methylene blue. After twelve hours cut lengthwise through the stem. The water, carrying the blue dye, has travelled *only in the wood.*

This can also be shown by 'ringing' a woody stem (see Fig. 71D). If a ring of bark and bast is removed all round the stem of a woody plant, e.g. a Castor Oil plant,† right down to the wood, water continues to pass up through the stem for a long time and the leaves remain fresh and firm as before. This shows that the water has travelled through the wood and not through the bast (which was removed by 'ringing'). In a few weeks, however, the plant will die —but not for lack of water. We shall explain the reason for this later.

We shall study the internal* structure of plants in more detail in Book Four.

## TRANSPIRATION

The experiments described above show that leafy shoots 'suck' water up the wood vessels of the vascular bundles. The stream of water thus passing up a plant is called the *transpiration*† *stream*. Where does this water go to, and why have leaves such a 'thirst' for water?

In an earlier part of this chapter we showed that some of the water entering the leaf was used in making carbohydrates. But the amount that disappears in this way is very small when compared with the total amount of water passing into the leaf in the transpiration stream. The rest of this water does not remain in the leaf, but is lost to the surrounding air as water vapour. This loss of water vapour from the leaves is called *transpiration*.

During transpiration, water does not evaporate from the outer surfaces of the leaves; these are, you will remember, covered with the almost waterproof *cuticle* that is pierced by thousands of very tiny stomates. The water in the leaf evaporates from the wet cells into air spaces *inside the leaf*, and the water vapour then escapes through the stomates to the drier air outside.

## HOW DO LEAVES GIVE OFF WATER-VAPOUR?

It is very easy to show that leaves give off water-vapour. Place a few leafy shoots in a beaker of water and cover the surface of the water with a thin layer of oil so as to stop evaporation. Then cover the beaker and the leaves with a dry bell-jar as shown in Fig. 72. After standing overnight, drops of water appear on the inside of the jar. This water can only have been given off by the leaves, which have been *transpiring*. Most leaves give off large amounts of water in this way, by *transpiration*.

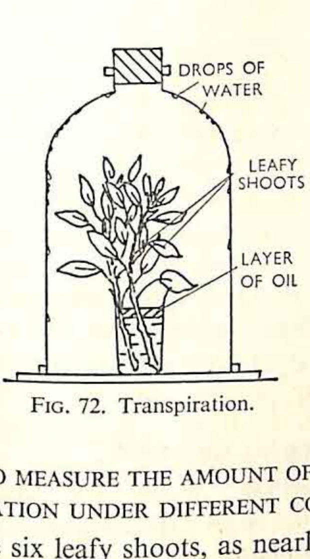


FIG. 72. Transpiration.

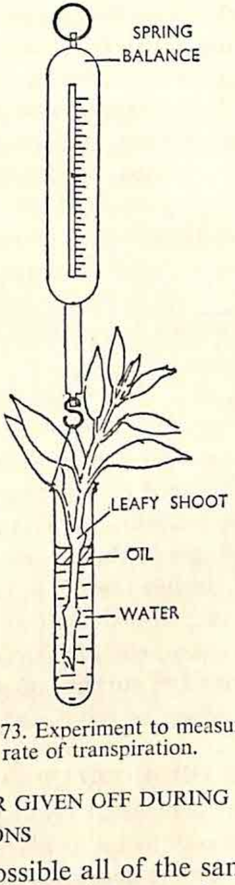


FIG. 73. Experiment to measure rate of transpiration.

HOW TO MEASURE THE AMOUNT OF WATER GIVEN OFF DURING TRANSPIRATION UNDER DIFFERENT CONDITIONS

Take six leafy shoots, as nearly as possible all of the same age and size, and with about the same total area of leaf-surface. Put them in six test-tubes half-filled with water (see Fig. 73). Pour a thin layer of oil on the surface of the water in each tube to stop evaporation, and then weigh each tube and shoot on a delicate spring balance, recording the weight below in each case. Put one test-tube and shoot in *bright sunlight*; put another in the *dark* (in a cupboard); another in a *strong wind* (using an electric fan if necessary); another in *still air*; another in *dry air* (under a bell-jar containing a dish of fused calcium chloride); and the sixth in *damp air* (under a bell-jar standing in a trough of water). Weigh each tube and shoot again after a few hours. It is found that all six have lost some weight, but the amount varies. The only way in which water can be lost from the test-tubes is by evaporation *from the leaves*, i.e. by transpiration, hence the loss of weight in each case measures the amount of water transpired.

| | LIGHT | DARK | WIND | STILL AIR | DRY AIR | DAMP AIR |
|---|---|---|---|---|---|---|
| ORIGINAL WEIGHT | gm. | gm. | gm. | gm. | gm. | gm. |
| FINAL WEIGHT | gm. | gm. | gm. | gm. | gm. | gm. |
| WATER LOST | gm. | gm. | gm. | gm. | gm. | gm. |

These six experiments show how the rate of transpiration varies under different conditions. *The rate of transpiration is greater (a) in strong sunlight, (b) in a strong wind, (c) in dry air*, and *(d) at higher temperatures* (although we have not done an experiment to show (*d*)). *Transpiration is most rapid in sunlight and in warm, dry, moving air. It goes on less rapidly in the dark and practically stops in cool, damp, still air.* In other words, transpiration, like evaporation from the surface of a pool, goes on most rapidly when the drying power of the air is greatest.

## WHAT IS THE IMPORTANCE OF WATER TO THE PLANT?

Water is of great importance to plants in one very special way. It swells out the living plant cells and makes them rigid or *turgid*.† All the softer, *non-woody* parts of plants, e.g. green stems, leaves, and flowers, are kept turgid by the pressure of their cell-sap. As soon as the water supply fails (e.g. when a young pot plant is not watered for several days) this *turgor* is lost, and the plant *wilts*.* If wilting is severe or very prolonged the plant dies. Under normal conditions, the amount of water lost from a turgid plant is equal to the amount taken up, so that what we may call the '*water balance*' remains constant. (As when our income* equals our expenditure* our bank balance remains constant.)

## IS TRANSPIRATION OF ANY VALUE TO THE PLANT?

The loss of water vapour from plants is a wasteful process, and it is doubtful whether a rapid stream of water passing from root to leaf serves any useful purpose. It has been suggested that the leaves are kept cool by the evaporation of water from their cells. When water changes from liquid to vapour, heat is taken from the water and its surroundings. Our knowledge of this fact is applied in the canvas* water-bag and the porous water-pot, both of which are cooled by evaporation. Warm-blooded animals, also, regulate their body-temperature in this way. On a hot day the animal's sweat-glands† pour out large quantities of a dilute salt solution ('sweat') on to the skin. If the air is fairly dry, this sweat evaporates and the body is cooled.

Plant leaves are often exposed to the full force of the hot sun. Only a small proportion of the light energy that falls on the leaf is used in photo-synthesis. A much larger proportion of the light energy is absorbed by the leaf and, being changed into heat energy, raises the leaf temperature. But the thin green leaves never get very hot. If they did, they would die, because most protoplasm is killed by temperatures between 50° C. and 60° C. They remain cool because they lose heat by the physical processes of radiation,† convection,† and conduction† (which we shall learn about later in Book Three), and also by transpiration. Experiments show that transpiration is not of much importance in this cooling process; it is even a danger because leaves are much more likely to be killed by lack of water than by high temperatures. It is worth noting that the leaves of many fleshy plants that live in hot, dry deserts, and which are exposed to strong sunshine, transpire very slowly and yet are not harmed by high temperatures.

Although the transpiration current may help to move substances about the plant (e.g. mineral salts and sugar), many scientists now believe that *transpiration is a disadvantage to plants and that, in dry climates at least, it may often be a source of great danger.* The actual amount of water lost can be very great. Experiments, in which large potted plants were weighed at intervals, have shown that a single plant of maize* may lose as much as 54 gallons of water by transpiration during its growing season. This means that an acre of maize in a normal crop may lose 1,300 tons of water in a season—the equivalent of 11 inches of rain over the same area. Such plants, during the hottest time of the year, often lose twice their own weight of water each day.

You will probably wonder why plants lose so much water to no purpose. The answer to this question, as far as we know at present, is that plants *cannot help losing water*. If leaves are to carry on *photo-synthesis* properly they must be exposed to the air and to bright sunlight and they must be able to use the carbon dioxide in the air. Now if carbon dioxide can get into the leaf through the open stomates, water vapour can also get out. And as the leaf cells have wet cell-walls, a leaf that is exposed to sunlight must lose water by evaporation and by the escape of water vapour through the pores in the leaf-skin. As long as the plant can obtain a supply of carbon dioxide from the air it must lose water at the same time.

### HOW SOME PLANTS REDUCE LOSS OF WATER

Plants are not entirely helpless against the danger of losing too much water. The guard-cells enclosing the stomatal pores are so built that they can move and close the pores. This closing often takes place when the plant has lost so much water that it begins to wilt (e.g. in the early afternoon of a very hot, dry day). Once the stomates have closed, the leaf can only lose water through its cuticle, and when this is thick (as it usually is in plants adapted to live in dry climates) it is practically water-proof.

### DROUGHT-RESISTING PLANTS

Up to now we have studied, as our examples, cultivated plants with thin, broad, flat leaves. Many of these plants come from countries of high rainfall. Such plants are uncommon under dry conditions, where most of the native plants have fairly hard or leathery thick leaves, small, narrow, needle-like or rolled leaves, or very thick, fleshy, or 'succulent'† leaves (see Fig. 74). Such plants are described as 'drought* resisting'.

If you do not water thin-leaved garden plants in hot, dry weather, they may wilt and even die. This is because they continue to lose some water through their thin leaf-cuticle even when the stomates are shut, and their *protoplasm* is very sensitive to even a slight shortage in their water balance. But 'drought-resisting' plants survive even the driest of natural conditions, often in very dry soils and in places where they are competing with their neighbours for what little water is available. This behaviour, or *drought resistance*, is possible for two reasons:

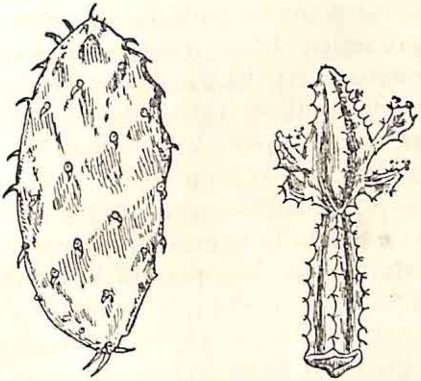


Fig. 74. Cactus stems.

(1) Although they transpire just as fast as thin-leaved plants while their stomates are open, once these are closed the thick cuticle prevents any further loss of water.

(2) Even when the water balance in these plants is seriously reduced they do not die, because their *protoplasm* is not very sensitive* to water loss. It is something like the protoplasm

in plant seeds, which can survive almost complete drying without injury.

It is necessary to emphasize here that these 'drought-resisting' plants are *not* always sparing with water. Under damp conditions they may lose just as much water as do the thin-leaved, delicate plants of our gardens. It is only when drought becomes severe that the special adaptations mentioned above become important. It must, however, be mentioned also that one group of drought-resisting plants—the fleshy 'succulents' or cactus-like plants—are actually sparing of water. Their stomates are often closed for most of the day, they have a very thick cuticle, and as a further adaptation they store water in their large fleshy leaves and stems. Such plants, however, usually grow comparatively slowly, as their carbon dioxide supply is also limited. Cactus† plants usually have a thick, flattened stem and branches that store water, while the leaves, in most cases, are little more than prickles.* Some kinds of Cactus can store a year's supply of water in their thickened stems, hence they can grow where other plants would die for lack of water. If a Cactus is given plenty of water, however, it can produce ordinary leaves. Casuarina† (..............) is a good example of a plant having small leaves that reduce transpiration, the leaves being reduced to tiny scales while the stomates are sunk in grooves.* What look like Casuarina leaves are really branches, as you will find on closer examination with a hand-lens. Some plants reduce the area of leaf that is exposed to dry air by rolling up their leaves. Sugar-cane, for example, rolls up its leaves in dry, hot weather, while young Banana and Caladium leaves are rolled up inside the older leaves, thus reducing the exposed surface.

The older leaves of Mango (................), Croton† (................), Rubber and Oleander† (................) all have a thick leaf-skin with the stomates sunk deep down in it, and this reduces transpiration. Cactus, Agave† (..............), and Yucca† (................), also, have very thick, tough skins on their green parts.

Some plants have hairy leaves that lessen evaporation by

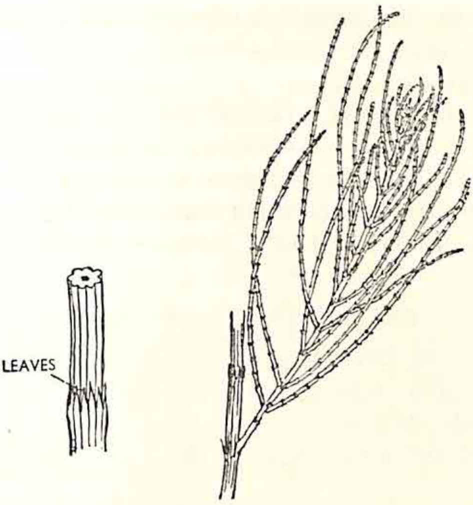


Fig. 75. Casuarina.

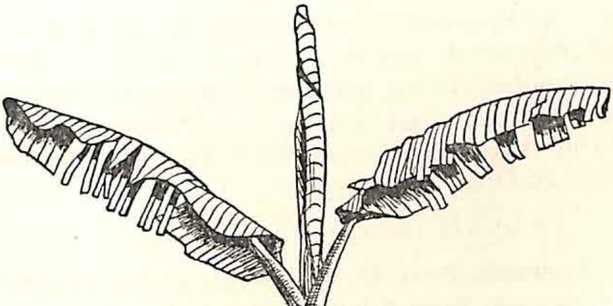


Fig. 76. Rolled leaf of banana.

preventing the air from blowing directly over the stomates, e.g. Geranium† (.................) and Water-Melon† (...........).

The leaves of some plants show a misty appearance on the surface that disappears when rubbed. This is due to a thin layer of wax that helps to reduce the loss of water from the leaf. Examples of such leaves are Caladium, Crinum (....................), Oleander, and Allamanda (................).

When leaves are held in a vertical position, they escape the full force of the Sun's rays, and transpiration is less rapid. Papaya† (................) turns its leaves in this way during the hot part of the day; while the young leaves of Mango and Cacao† (Cocoa†.................) are also held vertically.

## RESPIRATION IN PLANTS

In Book One we learnt that all *living things feed*, *breathe*, *and grow*, and we shall now show by experiment that plants (like animals) breathe, taking in oxygen from the air and giving out carbon dioxide and water-vapour. We have seen that, in *photo-synthesis*,

$$\text{CARBON DIOXIDE} + \text{WATER} + \underset{\textit{light}}{\text{ENERGY}} \longrightarrow \text{CARBOHYDRATES} + \text{OXYGEN}$$

so that carbohydrates contain *more energy* than the carbon dioxide and water from which they were formed. All plant growth and movement requires *energy*, and the plant sets free the chemical energy stored up in its carbohydrates *by oxidation*. We have also seen that when sugar, starch, and other plant materials burn in air, *heat energy* is set free; for example:

$$\text{SUGAR} + \text{OXYGEN} \longrightarrow \text{CARBON DIOXIDE} + \text{WATER} + \text{ENERGY } (\textit{heat and light})$$

Plants and animals, however, can *oxidize* their food material at a low temperature, without burning it rapidly with flame, and so set free the chemical energy it contains. This process of slow oxidation is called *respiration*, and it supplies the energy required for all plant activities *other than photo-synthesis*.

It is important to remember, however, that the term 'respiration' is not merely another word for 'breathing'. *Breathing means only the exchange of oxygen and carbon dioxide between living things and the atmosphere. Respiration means the whole process during* *which food is oxidized and energy is set free for the use of the plant (or animal).*

### HOW TO SHOW THAT ALL PARTS OF PLANTS BREATHE

(i) Take six gas-jars and pour a little water into each jar so as to form a layer about $\frac{1}{4}$ in. deep (see Fig. 77). Then put various living plant parts into the first five jars, as follows: (1) *germinating* (soaked) *seeds*, (2) *opening flowers*, (3) *ripening fruits*, (4) *underground parts* (e.g. small potatoes), (5) *leafy shoots*. Use sufficient plant material to fill about one-third of each jar. The sixth jar contains no plant material and serves as a '*control*' *experiment*. A short, wide test-tube, containing some clear lime-water and handled by a piece of thread, is now placed in each of the six jars. All the jars are closed with gas-jar covers (greased to make the jars air-tight), and those containing *green* parts of plants are put in a dark cupboard (so that photo-synthesis cannot take place). After several hours the jars are examined and it is found that the lime-water in jars 1–5 has turned chalky, showing the presence of carbon dioxide, and in these five jars a lighted candle is quickly extinguished, showing that some or all of the oxygen has been used up. In the sixth jar (the *control experiment*) the lime-water has not turned chalky and a lighted candle continues to burn for some time. Hence, all the plant parts have taken in oxygen and have given out carbon dioxide, i.e. they have been *breathing*.

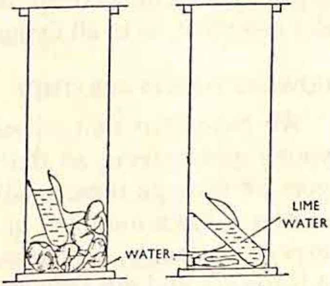


FIG. 77. Respiration in plants.

(ii) We must now do another *control experiment* with *dead* plant parts that have been killed by dropping them into boiling water. Repeat Experiment (i), using dead plant material and adding a few drops of thymol† solution to each jar to prevent decay and growth of moulds. Notice that these *dead* plant parts produce no change in the composition of the air inside jars 1–5.

It is very important to be quite clear that two opposite processes are taking place at the same time in green leaves in sunlight—*respiration* and *photo-synthesis.* During *respiration* the leaves use up oxygen and produce carbon dioxide. During *photo-synthesis* they use up carbon dioxide and produce oxygen. But *in bright sunlight* photo-synthesis is a much more rapid process than respiration (sometimes fifty times more rapid), hence it is only in the dark, when photo-synthesis stops, that we notice green leaves breathing. Actually, *respiration goes on in green leaves all the time, day and night*, as in all living things.

### HOW DO PLANTS BREATHE?

We have seen that *stomates* are found in leaves, flowers, and young green stems, so that in these parts of the plant breathing goes on through these small pores in the skin. Inside the leaf and stem are large numbers of tiny air-spaces, as we showed in our experiment on p. 113, when we forced in air at the cut end of a leaf-stalk and out through the stomates.

Older stems and roots, which are not green, have no stomates; but in their place they have small openings in the *bark*, loosely packed with grains of cork. These openings are called *lenticels*† and, unlike stomates, they are always open. Lenticels can be seen by the unaided eye, without even using a hand-lens, on the older shoots of many plants, e.g. Annatto.† A bottle-cork shows very long lenticels running at right angles to the length of the cork, which therefore makes an air-tight stopper.

In land plants the gases have to pass through the wet cell-walls after they have dissolved in the water in this cell-wall. Water plants that live beneath the surface have no stomates, and the gas exchange due to respiration (and photo-synthesis) goes on between the leaf-skin cells (which usually lack the gas-proof cuticle of the land leaf) and the water in which the plant lives. That is, these plants get their oxygen from that *dissolved* in the surrounding water and they give up carbon dioxide to the water also. In the light, a green water-plant is carrying out photo-synthesis as well as respiration and the net result is that it takes carbon dioxide from the water and liberates* oxygen. This often comes out of solution and appears on the leaves as bubbles that help the plant to float near the surface, where the light is brightest.

### HOW TO SHOW THE PRESENCE OF LENTICELS IN AN OLDER STEM (OR ROOT)

Use the apparatus shown in Fig. 78, passing a piece of an older brown stem (e.g. Tamarind† . . . . . . . . . . . . . . . .) through the cork, and sealing with wax the cut end that is inside the jar. When the jar is connected to a suction-pump (or if the exposed end cf the stem is connected to a bicycle pump) bubbles of air escape from a number of points on the surface of the stem, showing the presence of small openings (lenticels) through which air can pass. We see, therefore, that *there are air-spaces throughout the inside of the plant*, so that oxygen which enters through the stomates and lenticels can

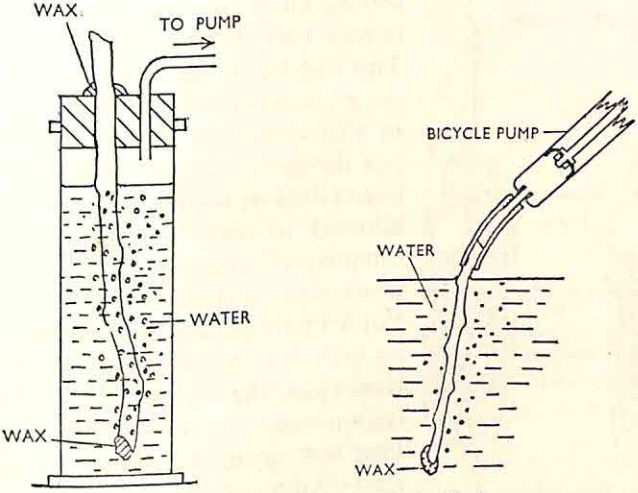


FIG. 78. Forcing air through lenticels.

reach every part of the plant where it is used for respiration. The carbon dioxide that is formed passes out to the atmosphere along the same path.

### HOW TO SHOW THAT HEAT IS SET FREE DURING RESPIRATION

When you run about you breathe more rapidly than when you are resting, because more of your food must be oxidized to supply the extra energy. Similarly, when a plant is growing rapidly, e.g. during germination, it is in a state of increased activity, so its respiration is more rapid and some of the energy that is set free appears as heat. This can be shown as follows: Put some germinating seeds on damp cotton-wool in a vacuum-flask, and in a similar flask put the same number of seeds that have been killed by boiling and have then been allowed to cool. (N.B.—Add a small quantity of phenol† or thymol to these dead seeds to stop them from decaying.) Put a thermometer in each flask so that its bulb is surrounded by the seeds, and then close the mouth of the flask with cotton-wool, as shown in Fig. 79. No heat will be able to enter the vacuum-flasks from outside, and any heat that is set free inside will be unable to escape. Read the thermometers at intervals for the next few days. It is found that *the germinating seeds are one or two degrees warmer than the dead seeds*, showing that *heat is set free during respiration*.

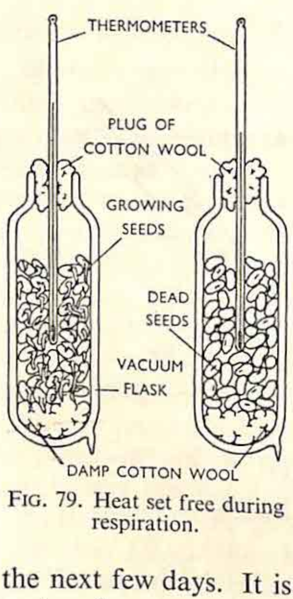


FIG. 79. Heat set free during respiration.

When growth is slower, respiration is less rapid and less heat is set free. Under such conditions, this heat is quickly lost to the surrounding air, and the plant remains at practically the same temperature as its surroundings.

Most plants, during their early stages of growth, produce only roots, stems, and leaves. Later on in their life-history, however, they usually produce *flower-buds*, which open out later into *flowers*. A flower does not last very long, but after it has been open for some time the greater part of the flower withers* away. One part of the flower usually remains behind, however, and this part grows in size and becomes the *fruit*, which contains the *seeds*.

The work of the flower is quite different from that of the root, stem, and leaves, which are mainly concerned with feeding and growing. *The sole function* of the flower is to reproduce the plant.*

We shall now examine the structure of a common flower, learning the names of the different parts and what each part does. As our first example we shall take the Hibiscus flower (.........). Dissect it carefully, examining the smaller parts with a hand-lens before making drawings of them.

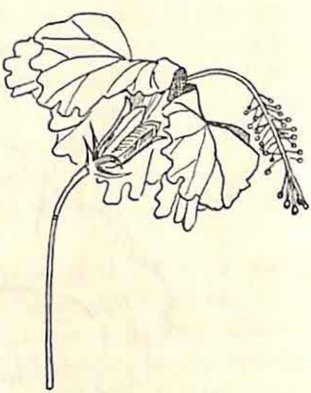


FIG. 80. Hibiscus flower.

THE PARTS OF A FLOWER

The Hibiscus flower grows at the end of a *flower-stalk*, which arises in the axil of a leaf. The flower itself is really a very short stem that bears, instead of green leaves, four special kinds of *modified leaves*.

*Calyx and Sepals.*—Beginning at the lowest and outermost part of the flower we find two rings of small green leaves. The inner ring consists of five larger green leaves, each of which is called a *sepal*.† The complete set of five sepals is called the *calyx*,† and this cup-like structure encloses and protects the inner parts of the young flower when it is in the bud. The outer ring of smaller green scale leaves or *bracts*† (which vary in number in different Hibiscus flowers) is called the *epi-calyx*† (since it grows upon the true calyx).

*Corolla and Petals.*—Just above and inside the calyx is a ring of five large, coloured leaves called *petals*.† These five petals, taken all together, form the *corolla*.† As in most other flowers, the funnel-shaped corolla is the most striking part of the flower, the petals being large and brightly coloured, thus attracting insects to the flower.

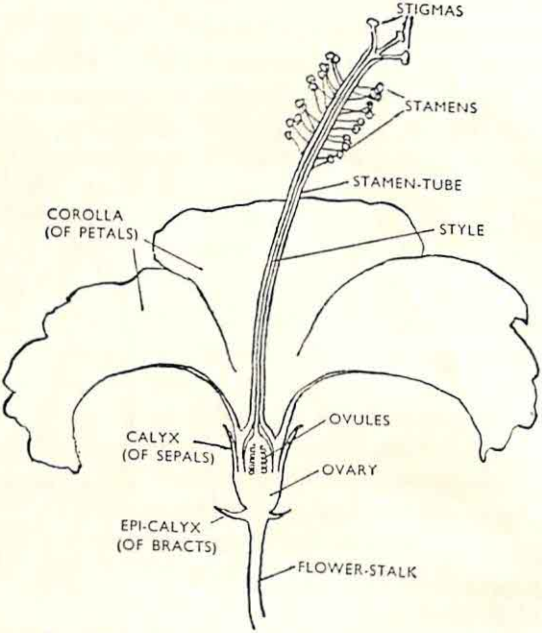


FIG. 81. Hibiscus flower in longitudinal section.

*Stamens.*—Inside the corolla there are numerous *stamens*,† each consisting of a thin *stamen-stalk* with a swollen club-shaped *stamen-head* containing numerous yellow *pollen-grains*, which are set free when the stamen-head ripens and splits open. In the Hibiscus flower, the stamens are arranged in an unusual way with their stalks all joined together at the bottom to form a *stamen-tube*. At the top, the stamens are separate and hold out their heads at different heights.

*Pistil*.—In the centre of the flower is the *pistil*.† This consists mainly of a swollen *seed-box* (or *ovary*†) which when cut across is seen to be divided into five sections, each containing numerous *ovules*†, which later develop into *seeds*. From the top of the *ovary* arises a thin stalk called the *style*,† which runs up through the middle of the *stamen-tube* and then branches at the top into five red knobs* called *stigmas*.† These serve to receive pollen. The *pistil* is a very important part of the flower since it contains the *ovary*, which finally becomes the *fruit*, containing the *seeds*. The pistil remains attached to the plant until the seeds are ripe, long after the rest of the flower has withered.

A complete flower is really a special kind of shoot, with pistil, stamens, petals, and sepals instead of ordinary green leaves.

The best way of describing a flower is to draw it in *longitudinal*† *section*, i.e. as seen when cut through lengthwise, down the middle (see Fig. 81). Your teacher will show you the proper way to do this. It is also necessary to cut across the *ovary*, cross-wise, in order to describe its structure.

### HOW DO FLOWERING PLANTS REPRODUCE THEMSELVES?

The *ovary* contains *ovules* that later become *seeds* if certain things happen. The first step towards the formation of seeds is *pollination*,† i.e. when pollen from the same kind of flower is put on the ripe stigma. The next step is when a *pollen-grain* on the stigma grows out into a very fine thread or *pollen-tube* growing down through the style into the ovary and finally entering one of the ovules (see Fig. 82). Inside the tip of this

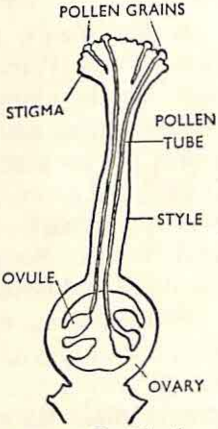


FIG. 82. Fertilization.

pollen-tube is produced the *male reproductive cell*, and this unites with the *female reproductive cell* (the *egg-cell* or *ovum*†) *inside the ovule*. This process is the true *fertilization*† and it must not be confused with *pollination*, which is only one step leading to fertilization. After the egg-cell is fertilized, it grows into an *embryo*,† still inside the ovule, which develops into a *seed*.

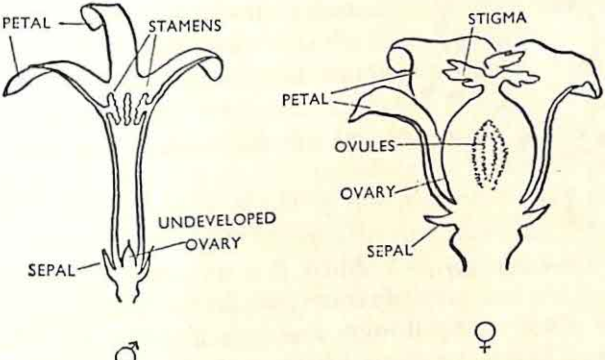
### WHAT IS THE DIFFERENCE BETWEEN SELF-POLLINATION AND CROSS-POLLINATION?

If the pollen that reaches a stigma comes from the stamens of the same flower (or from another flower *on the same plant*), then the flower is said to be *self-pollinated*, but if the pollen comes from a flower on *another plant* of the same kind then the flower is said to be *cross-pollinated*. As a general rule, the best seeds, which yield the healthiest and most vigorous plants, are those formed by *cross-pollination*, and many plants have *flowers that favour cross-pollination rather than self-pollination*.

### SOME FLOWERS THAT ARE ALWAYS CROSS-POLLINATED

A few plants, e.g. Palmyra Palm† (. . . . . . . . . . . . . . . .) and Screw-Pine† (Pandanus† . . . . . . . . . . . . . . . .), have separate 'male' and 'female' plants. The 'male' plants bear flowers that produce only stamens, while the flowers on the 'female' plants produce pistils but no stamens. In such plants, therefore, self-pollination is quite impossible, and it is useless to grow a female plant by itself without any male plant within a reasonable distance, for both 'male' and 'female' flowers are necessary if the female plant is to be fertilized and bear fruit.

Some plants, e.g. Maize (. . . . . . . . . . . . . . .), Coconut Palm† (. . . . . . . . . . . . . . . .), Papaya (. . . . . . . . . . . . . . . . .), and Oil Palm† (. . . . . . . . . . . . . . . .), produce two kinds of flowers on the same plant: 'male' flowers with only stamens, and 'female' flowers with pistils but no stamens. In such plants the 'male' and 'female' flowers usually ripen at different times, e.g. in Maize, the 'male' flowers set free their pollen before the stigmas of the 'female' flowers are ripe, so that self-pollination is rare.



(*a*) Section of male flower. (*b*) Section of female flower.

FIG. 83. Papaya flowers.

In most plants that bear '*complete*' *flowers* (containing both stamens and pistil in the same flower) the stamens and stigmas are not ripe at the same time. Sometimes the stamens have set free their pollen before the stigmas have become sticky, while in other cases the stigma is ready to receive pollen before the stamens in the same flower are ripe. Both arrangements clearly favour cross-pollination.

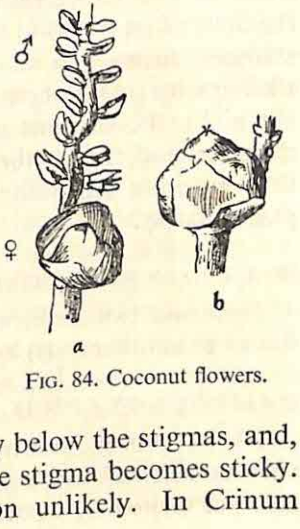


FIG. 84. Coconut flowers.

Many flowers have their stamens and stigmas of different length so that they are kept well apart.

In such flowers the stamens are usually below the stigmas, and, in addition, only the upper surface of the stigma becomes sticky. This arrangement makes self-pollination unlikely. In Crinum

(. . . . . . . . . . . . . . . .), for example, the stigma sticks up well above the stamens and the latter hang outwards away from the stigma, so that there is little chance that the stigma will touch the stamens and receive their pollen. Gloriosa† (Climbing Lily† . . . . . . . . . . . . . . . .) shows a similar arrangement (see Fig. 85).

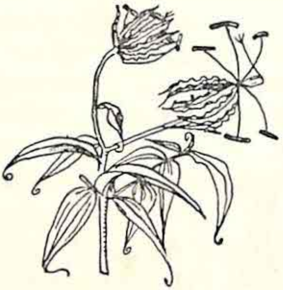


FIG. 85. Gloriosa flowers.

### HOW SOME FLOWERS ARE SELF-POLLINATED IF CROSS-POLLINATION FAILS

Most flowers are arranged so as to favour cross-pollination; but if this does not take place, many flowers can be self-pollinated. In a Sunflower† (. . . . . . . . . . . . . . . .), which we shall study later (see p. 142), the stigma bends over as the flower gets older until its sticky inner surface touches the stamens of the same flower, so that it becomes self-pollinated (if cross-pollination has not taken place already). In the Four o'Clock Flower† (Mirabilis† . . . . . . . . . . . . . .), when the flower first opens in the evening the stigma is ripe but not the stamens, hence if a moth† comes from another Four o'Clock Flower with ripe stamens, cross-pollination will take place. During the night, the stamens grow in length and ripen and the flower closes up and presses the heads of the stamens against the stigma, thus ensuring self-pollination if cross-pollination has not taken place already.

### HOW POLLEN IS CARRIED FROM ONE FLOWER TO ANOTHER

There are two main ways in which pollen is carried from one flower to another:—(i) by *insects*, and (ii) by the *wind*.

### POLLINATION BY INSECTS

We have only to watch the flowers in a garden to see that various kinds of insects visit flowers. As a general rule, the flowers that are visited by insects are *brightly coloured* and have a *sweet* *smell* that attracts insects. Insects, however, do not visit flowers merely because they like bright colours and sweet smells, but because such flowers also contain the sugary liquid called *nectar*. Many insects, and some birds, feed on nectar, while bees convert* it into *honey*. Bees also collect pollen, which they mix with honey to feed the young bees during the first few days of their life. Since one single pollen-grain is all that is needed to fertilize one ovule, the plant can spare the pollen that is collected by bees if an occasional pollen-grain is put on the stigmas of its flowers. The nectar is usually produced deep down in the flower, so that while the insect is getting the nectar it is sure to be dusted with pollen. Then, when this insect goes to another flower of the same kind whose stigma is ripe, pollen will be left on the stigma and the flower will become cross-pollinated. If you watch flowers carefully, you will find that different kinds of insects visit various kinds of flowers, and that some insects visit only one kind of flower on one journey, thus favouring the exchange of pollen between flowers of the same kind.

In general, when we see a flower with a *bright colour*, a *smell*, and *nectar*, we know that it is most probably pollinated by *insects*: or in the case of some tropical flowers, by *birds*, e.g. Sun-Birds,† Humming-Birds† and Flower-Suckers.† Smell is particularly important for flowers that are pollinated by night-flying *moths*. Such flowers, also, are usually white or light-coloured.

### POLLINATION BY THE WIND

There are many flowers, however, that are not brightly coloured, that have no smell, and that produce no nectar, e.g. grasses and many palms. Such flowers are adapted for pollination by the *wind*, which carries the light, dusty pollen from the stamens of one flower to the stigmas of another. They produce very large quantities of pollen, much of which will be wasted, never reaching the right kind of flower. The pollen of these wind-pollinated flowers, also, consists of very small, light, dry, powdery grains; while the pollen-grains of insect-pollinated flowers are usually larger and rough-surfaced so that they cling to the hairs on an insect's body.

The stamens of wind-pollinated flowers usually hang outside the flowers on long, thin, and very flexible stalks so that the pollen is easily carried away by the wind. The stigmas of wind-pollinated flowers, too, are usually long, branching, and feathery, and thus offer a large area to catch pollen floating in the air. A typical wind-pollinated flower is Maize, which we shall examine later (see p. 144). At the top of the plant is a bunch or 'tassel'† of many 'male' flowers, containing only stamens and producing very large quantities of dry, powdery pollen. The 'silks' that grow from the top of the young cob are the long stigmas of the 'female' flowers.

## MORE COMMON FLOWERS

### THE CRINUM FLOWER

There are many tropical varieties of Crinum and related kinds of Lily (e.g. Hymenocallis†), growing wild and also in gardens. All the year round, the plant has a bunch of long, narrow, thick, dark green, waxy leaves, arising from a *bulb*; and a long, thick flower-stalk grows up among the leaves, bearing a number of white flowers at its upper end. There is a ring of scale-leaves, or *bracts*, at the top of the flower-stalk, serving to protect the flowers when they are in bud.

The outer part of each individual flower consists of six white petal-like leaves, and there are no green sepals. It is probable, however, that three of the white flower-leaves are really sepals and the other three are petals. In such cases, where the calyx and corolla are so closely alike in shape, size, and colour, we refer to the whole structure as a *perianth.*† These six white perianth-leaves join together at their bases and form a tube, several inches long. The lower part of this *perianth-tube*, where it joins the flower-stalk, is swollen and contains the ovary. When cut across, the ovary is seen to consist of three cavities*, each with two rows of tiny ovules attached to the centre of the ovary. Arising from the top of the ovary and running upwards through the perianth-tube is the long green style, sometimes more than six inches long. At the upper end of this style is a small knob—the stigma—which produces a drop of sticky liquid when it is ripe, so that pollen sticks to it. Growing out of the inner surface of the perianth-leaves are six long stamens—one to each perianth-leaf, with their heads,

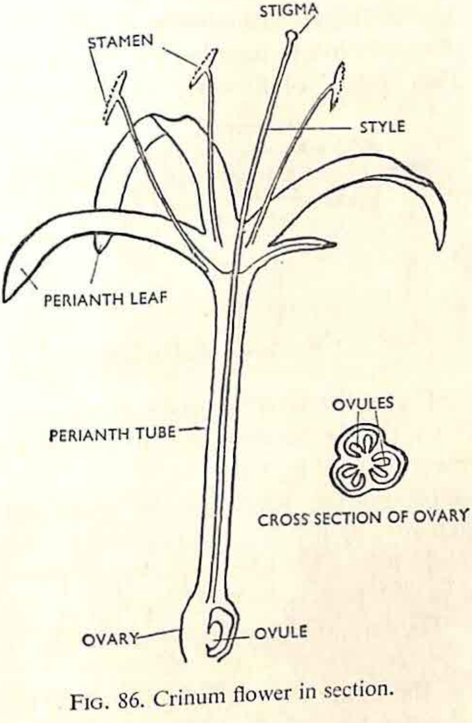


FIG. 86. Crinum flower in section.

which are sometimes an inch long, attached to the stamen-stalks at their mid-point. In some kinds of Crinum, the lower parts of the stamen-stalks are joined together by a funnel-shaped white structure that holds the stamens well apart in the flower and away from the stigma.

(It will be noticed that the parts of this flower are arranged in *threes* or *sixes*. This is characteristic of *Monocotyledons*†. Dicotyledons† have flowers with their parts usually in fives, but *never in threes or sixes.*)

### THE SUNFLOWER

The first thing to notice about the Sunflower is that it is not a single flower, but a 'head' containing a very large number of small flowers grouped closely together on the flattened end of the flower-stalk. This 'head' of flowers, which is surrounded by a large number of green *bracts*, contains two kinds of flowers: (i) *ray-flowers*† round the outside and (ii) *disc-flowers*† inside the ring of 'ray-flowers' (see Fig. 87).

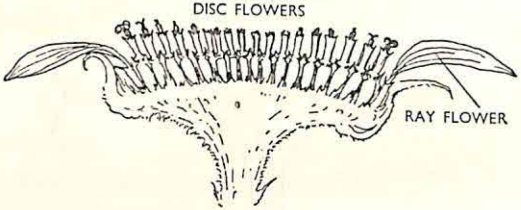


FIG. 87. Sunflower head in section.

Round the outside of the 'head' are the larger and more striking *ray-flowers*, each of which has a strap-shaped coloured part that looks like a petal. Actually, this strap-shaped part consists of five narrow petals joined together. The ray-flowers serve mainly to attract insects. They frequently contain no stamens and sometimes even no pistil (see Fig. 88 A).

The middle of the Sunflower 'head' consists of large numbers of tube-shaped *disc-flowers*. These are *complete* flowers, with both stamens and pistil, and they can produce seeds. A disc-flower may have two hair-like sepals, and the corolla forms a tube with the tips of the five petals showing at the top. There are five stamens with their heads joined together to form a stamen-tube, inside which the pollen is set free (see Fig. 88 B).

In a young Sunflower 'head', the first disc-flowers to open are those round the outside of the 'head', nearest the ray-flowers, and the stamens appear first, before the stigma. As the stigma grows up inside the stamen-tube, it pushes out the pollen, forming a little heap on top of the disc-flower. A few days later, after the style has grown still longer, the stigma stands out above the stamens; but it is still closed up so that pollen cannot reach the sticky inner surface and thus bring about self-pollination. The stigma is divided into two halves that are sticky only on their inner surfaces. A little later, these two halves curl outwards so that pollen can be received from another Sunflower, carried by insects that crawl over the Sunflower 'head' (see Fig. 88 C). In this way the Sunflower may be cross-pollinated. As the disc-flower becomes still older, the two halves of the stigma curl right round until they touch the stamens of their own disc-flower, so that if cross-pollination has failed self-pollination can take place (see Fig. 87).

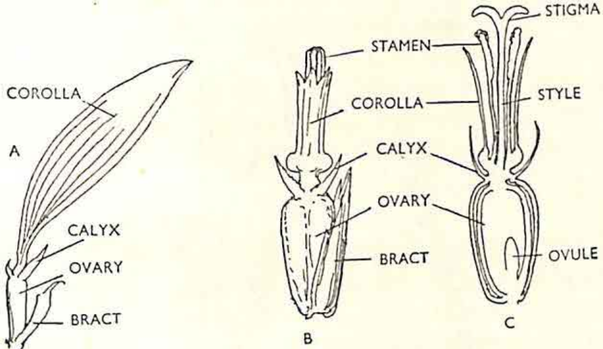


FIG. 88. A, Ray-flower; B, Young disc-flower; C, Older disc-flower in section.

This type of flower always forms seeds, and this is one reason why such '*composite* flowers*' form the largest and most successful family of flowering plants on the Earth's surface.

### THE MAIZE FLOWERS

The flowers we have studied up to the present have all been adapted for pollination by insects. We shall now examine Maize flowers as an example of flowers that are adapted for *wind-pollination*. Maize is a *grass* in which the stamens and pistils are in separate flowers, both 'male' and 'female' flowers growing on the same Maize plant (see Fig. 89).

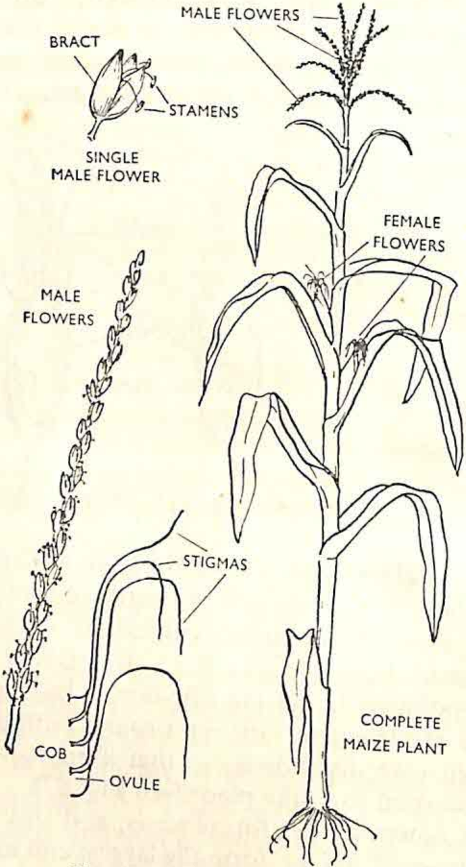


FIG. 89. Maize plant and flowers.

The '*tassel*' consists of '*male*' *flowers* only, produced on long stalks at the top of the plant. The stamens have very thin stalks and hang out between the *bracts* so that they swing easily in the wind and set free their pollen. The stamens produce very large quantities of light, dry, dusty pollen. (Notice that there are no sepals or petals—only bracts.)

The *'female' flowers* are arranged in parallel rows on a cob enclosed in a sheath* of many large overlapping bracts. Each single 'female' flower consists of an ovary with a long, thin stigma, several inches long. The stigmas (or 'silks') hang out from the top of the overlapping bracts (or the 'husk'†) looking like a bunch of silky threads. Maize depends on the *wind* to carry pollen from the 'male' to the 'female' flowers. Since the 'male' flowers are ripe before the 'female' flowers, *cross-pollination* usually takes place.

## FRUITS AND SEEDS

After fertilization, the *ovule* ripens and develops into the *seed*, and at the same time the *ovary* also ripens and grows into the *fruit*. *As a general rule, therefore, we can regard a seed as a ripened ovule and a fruit as a ripened ovary*, although there are occasional cases where other parts of the flower may take part in forming the fruit. The scientific meaning of '*fruit*', therefore, is not merely 'something to eat'.

There are many different kinds of fruits, but they all contain seeds that *reproduce* the plant. In most cases, these seeds are produced *in large numbers*. This allows for wastage of the delicate young seedlings, for a large proportion of seeds fall where the conditions for germination and growth are unfavourable. In most fruits there is some means of *scattering* the seeds and thus *dispersing** the plant.

Fruits are sometimes classified as either *dry fruits* or *fleshy* fruits. Dry fruits have a tough or woody outer layer. Some of them do not split open when ripe, e.g. Sunflower and other 'composites', nuts, Maize, and other grains and grasses. Peas and Beans are examples of dry fruits that split open when ripe, throwing out their seeds. Other common dry fruits that split open are Balsam, Rubber, Castor-oil,† and Aristolochia† (..............).

Fleshy fruits have a soft, juicy part surrounding the seeds, e.g. Mango, Papaya, Tomato,† Orange: in fact, all our cultivated fruits are of this type. In Nature, birds and other animals eat the fleshy part and drop the seeds some distance from the parent plant.

## HOW FRUITS AND SEEDS ARE SCATTERED

The main ways in which fruits and seeds are scattered are (i) *by the wind*, (ii) *by animals*, (iii) *by water*, and (iv) *by mechanical means*, e.g. the dry fruit bursts open suddenly and throws the seed for several yards.

A plant that scatters its seeds widely can spread to places where its offspring* will have a better chance of survival. The largest seeds have a larger store of food for the young plant but are less easily scattered; the smaller seeds are more easily scattered but contain less food to give the new plant a good start in life.

## HOW SEEDS ARE SCATTERED BY THE WIND

(*a*) Some fruits and seeds have large, thin surfaces that serve as 'wings' and enable the wind to blow them some distance from the parent plant before they fall to the ground. Examples of such *winged seeds* are Aristolochia, Bignonia† (. . . . . . . . . . .), Petrea† (. . . . . . . . . . . . . .), and many tall forest trees (see Fig. 90).

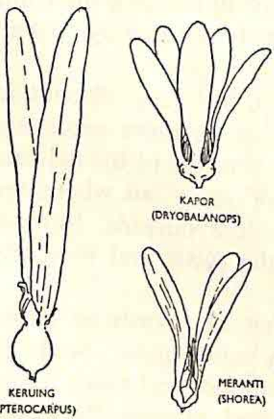


FIG. 90. Winged seeds.

(*b*) Some fruits have a bunch of long, silky hairs attached to them so that they 'float' in the air. Such *'parachute'† fruits* can be carried very long distances by the wind, e.g. Lalang (. . . . . . . . . . .), Kapok† (Silk-Cotton. . . . . . . . . . . . .). Parachute fruits are common among plants with 'composite' flowers.

(*c*) Some seeds, e.g. those of Orchids, are so very small and light in weight that they can be blown away by the wind.

(*d*) Other plants, e.g. Poppy† (. . . . . . . . . . . . .) and Aristolochia

(............), have fruits that swing in the wind and thus shake out their seeds when ripe. (You should collect any fruits or seeds you find that can be scattered by the wind and bring them to school and make drawings of them.)

## HOW SEEDS ARE SCATTERED BY ANIMALS

(*a*) One way in which plants make use of animals to scatter their seeds is by having fruits with hooks or prickles that will catch in the hair or feathers of passing animals and be carried away. Sooner or later these seeds are brushed off again, usually at some distance from the parent plant. Some grasses have hooked fruits of this kind; another example is Urena† (..............). N.B.—Prickles on fruits are not always a means of scattering the fruit: in some cases they *protect* the young fruit from animals until it is ripe, e.g. Rambutan,† Annatto (..................).

(*b*) Most fleshy fruits are searched for by some animal that likes to eat the juicy part. Birds, bats,† rats,† mice, and other animals as well as human beings carry off these fleshy fruits for food and drop the seeds some distance away from the parent plant. There are very many examples of such fruits: Mango, Orange, Lime, Pummelo,† Tomato, Sapodilla† (..............), Durian,† Papaya, Rambutan, Soursop† (....................), Melon (..............), Custard-Apple† (..................), Bullock's Heart† (..............), Jack-Fruit† (............), Mangosteen† (..............), and you should be able to think of many others.

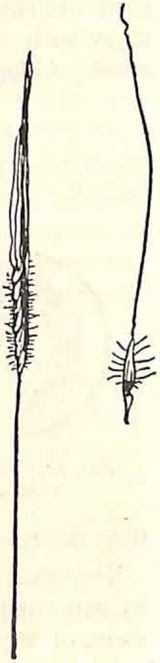


FIG. 91. Hooked grass seeds.

Some of these eatable fruits have the seed enclosed in a hard covering or 'stone' so that an animal can only eat the juicy part outside and will drop the 'stone' containing the seed. In other eatable fruits, e.g. Guava† (..............), the seeds are quite small and can be swallowed by animals, but, since the seeds have a covering that is not digested,* they pass through the animal's food-canal unchanged and without damage. Birds and bats eat the juicy parts of such fruits, swallowing the small seeds and then scattering them far and wide with their droppings.

In other cases, e.g. grasses, the seed itself is eatable and can be digested by an animal. Such plants produce large numbers of seeds and a small percentage may be scattered, but most of them are eaten and digested. Animals, e.g. birds and ants, which carry such seeds to their nests or young ones always drop a few seeds accidentally and so scatter them.

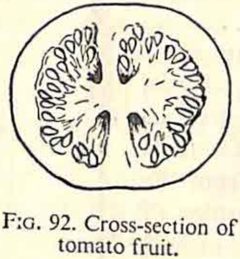


FIG. 92. Cross-section of tomato fruit.

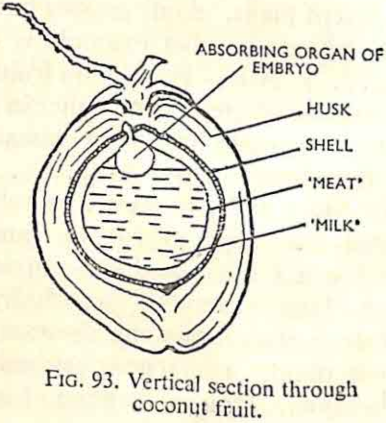


FIG. 93. Vertical section through coconut fruit.

### HOW SEEDS ARE SCATTERED BY WATER

The best example of a fruit that is specially adapted for dispersal by water is the Coconut. The Coconut Palm grows near the sea-shore of most tropical countries, and the fruit often falls where it can be carried away by the tide. The tough, fibrous *husk* outside the *nut* protects it from damage and enables it to float for long distances. For this reason, Coconut Palms are usually the first plants to appear on new coral islands. The nut has a large supply of food *and water*, so that the seed can germinate under unfavourable conditions, e.g. on a sandy shore (see Fig. 93).

Other examples of waterside plants with relatively large fruits having a fibrous fruit-covering containing air-spaces are Nipa† (..............), Barringtonia† (..............), Scaevola† (. ..............), and Heritiera† (..............).

### EXPLOSIVE FRUITS

Some plants are quite independent of wind, water, or animals for scattering their fruits, for their seeds are thrown out some distance from the parent plant by their *explosive fruits*,† e.g. Balsam, Rubber, Castor-oil. When the fruit is ripe and dry, it opens suddenly and throws out its seeds. Many plants whose fruit is a *pod* throw out their seeds in a similar way. When the pod is ripe and dry, it opens suddenly and the two halves twist round, thus throwing out the seeds. The fruit of the Sand-box† Tree explodes with a loud bang and throws out its large seeds to a distance of many yards. The fruit of the Squirting Cucumber is filled with liquid and when ripe the fruit breaks away from the plant, thus opening a pore at its base. As it falls, the contents squirt out, scattering the seeds to a considerable distance.

### FRUITS WITH NO SEEDS

Many eatable fruits have been cultivated by Man for so long that the character of the fruit has become very different from its original wild form. The eatable, fleshy part of the fruit has increased until, in some cases, the seeds have almost disappeared, e.g. Bananas, Pineapples, and 'Seedless Oranges'. Wild banana fruits are full of hard black seeds 5–6 mm. in diameter, so strong as to be dangerous to human teeth, and making the fruit almost uneatable.

Learning Exercises on Chapter V will be found on pp. 53–57 of *General Science Workbook I.*

# CHAPTER VI

## THE SOIL

Although the soil is only a comparatively thin layer covering parts of the Earth's surface, it is of very great importance because it supports all plant life. In regions where there is no soil there are no ordinary green plants, and we have seen that all animals depend on green plants. Hence a large area that is bare of soil is also bare of living things. The depth of the soil layer varies from a few inches to several feet, but these shallow deposits of soil on the Earth's land surface have taken many millions of years to form. We shall now learn something about this very important substance, *soil*: (i) *how it is formed*, (ii) *what it consists of*, (iii) *what plants get from it*, and (iv) *what factors make soil suitable for the growth of plants*.

Scientists believe that about three thousand million years ago (i.e. $3 \times 10^9$ years ago) the Earth separated from the Sun and became a great ball of exceedingly hot gas that gradually cooled down, becoming first liquid and then semi-solid (or plastic). The outer crust* then solidified, preserving the main outlines of its earlier plastic form in the shape of the mountains and continental land-masses that we know today. At this early stage of the Earth's history, the surface layer consisted of *igneous*† rocks formed by the cooling of hot liquid material. Granite is a common rock of this kind. Igneous rocks are sometimes called *primary*† *rocks*, because they were the first rocks to be formed. When this solid crust was first formed, about $2 \times 10^9$ years ago, there was no life on the Earth and no liquid water. Then, as the millions of years passed, the Earth's surface became cool enough for water vapour to condense on it, forming rivers, lakes, and seas, and the atmosphere was formed from the so-called 'permanent gases'—oxygen, nitrogen, helium, and neon. This stage of the Earth's history is the point from which scientists begin to measure '*geological*† *time*'.

## THE WEATHERING OF ROCKS

Once the Earth had an atmosphere and deposits of water on its surface, the '*Water Cycle*' started (see Book One, Chap. V) and, from then onwards, *soil was formed by weathering*†, i.e. by the action of weather changes in producing *rock decay*.

In cold and temperate climates, and in deserts, weathering is largely the result of *physical changes*. For example:

(*a*) running water wears away rocks, carries along the stones, and breaks them up into smaller and smaller pieces;
(*b*) wide changes in temperature produce alternate* expansion and contraction so that tiny cracks are formed in the rocks;
(*c*) since water expands on freezing, any small cracks are enlarged until the surface crumbles away;
(*d*) glaciers† (rivers of ice slowly moving down a mountain-valley) carry along rocks sticking in their under-surface, and so wear away material from the underlying rock;
(*e*) strong winds carry rock-dust and this wears away exposed rocks; and
(*f*) the roots of plants enter cracks in rocks and, as they grow, the cracks widen and pieces of rock split off. Their root-tips also produce organic acids that dissolve the rock.

In considering the action of frost† (freezing temperature) and glaciers, it is to be remembered that the climate in different parts of the world has not always been the same as it is today. There is evidence* that, in past ages, regions that now have warm climates were then very much colder.

In wet, tropical climates, where rainfall exceeds evaporation, *chemical changes* play an important part in weathering. In such regions the decomposition of organic matter produces carbon dioxide, and the steady downward movement of large quantities of rain-water, saturated with this carbon dioxide, dissolves most of the constituents of granite (even silica), leaving deep, but 'poor', soils containing much iron oxide and aluminium oxide†. These are called *lateritic soils*† and they are either red, yellow, or brown in colour. This chemical weathering of granite in wet, tropical regions is very rapid, and the various stages in its decomposition can be seen in many road cuttings. Under dense jungle, granite is sometimes weathered into *laterite* to a depth of 100 feet below the surface.

In drier and cooler climates the decomposition of organic matter in the soil stops at the formation of *organic acids* that do not dissolve silica from granite. The final product in such climates is a mixture of sand and clay, which makes better soils than the lateritic soils of wet tropical countries.

The type of soil in any area depends on the geological structure of the underlying rocks and upon the long-continued action of the local climate and vegetation.

## OTHER KINDS OF ROCKS

We have seen that igneous rocks are gradually weathered and broken down into small pieces. When this weathered material is carried along by running water in suspension, it is sorted out into particles of different sizes: *gravel* (small stones and coarse sand), *sand*, and *silt*† (mud). The larger pieces of rock are deposited first; and later, as the stream becomes wider and its flow slower, the finer suspended particles also settle down, forming *alluvial*† (flood) *deposits*. In places where very thick deposits have been formed in this way, the enormous pressure has changed the lower layers into hard rock once more. Rocks formed in this way from *sediment** deposited by water are called *sedimentary rocks*.† *Sandstone*† is a sedimentary rock consisting of grains of sand cemented together. *Mudstone*† is a partly-hardened mud, and *shale*† is a later stage. *Limestone*, *chalk*, and *coal* are examples of organic sedimentary rocks. Sedimentary rocks often contain *fossils*† (preserved remains of plants and animals).

Since the material that produced these sedimentary rocks was deposited from water, such rocks were usually formed in horizontal layers or *strata*,† although later movements of the Earth's crust may have thrown the original horizontal strata into *folds*. Strata are characteristic of sedimentary rocks and are not found in igneous rocks.

The third great class of rocks is that of the 'changed' or *metamorphic*† rocks. When sedimentary or old igneous rocks are made very hot, or compressed very strongly, they change into new types. This happens when rocks come into contact with hot melted rock, also when they are buried deeply, or strongly compressed during the mountain-building movements of the Earth's crust. The changed conditions cause changes in the original minerals, which re-crystallize in new, often denser, forms. Thus, after metamorphosis, sandstone becomes *quartzite*,† limestone becomes *marble*, and shale becomes *slate*.†

Metamorphic rocks may in their turn be weathered and form new sedimentary rocks.

To sum up, therefore, *igneous rocks* (e.g. granite) are the original rocks of the Earth's crust. They may be weathered to form soil or sedimentary rocks, and may also be changed by heat and pressure to form *metamorphic rocks*.

*Sedimentary rocks* (e.g. sandstone and limestone) consist of particles of sand or mud pressed together to form a rock. Such rocks may be weathered to form soil or new sedimentary rocks, or may be changed by heat and pressure into metamorphic rocks (e.g. sandstone to quartzite, and limestone to marble).

*Metamorphic rocks* (or 'changed rocks') have been formed by the action of heat and pressure on igneous and sedimentary rocks. Such metamorphic rocks may be weathered to form sedimentary rocks or to form soil.

Our main concern at the moment, however, is that *all three classes of rocks gradually form soil.*

## THE CONSTITUENTS OF SOIL

The best way to find out what soil consists of is to examine some actual soils, e.g. 'good' garden soil (or 'potting' soil) and 'poor' soil from an exposed clearing. Pick out any stones from your samples of soil and then weigh out, in two crucibles, 10·0 gm. of each kind of soil. Put the crucibles in an oven* kept at a temperature between 100 and 110 degrees C. so as to dry the soil gently. The loss of weight after twenty-four hours at this temperature represents the amount of free, uncombined *water* contained in the soil.

| | *'Good' soil* | *'Poor' soil* |
|---|---|---|
| Weight of crucible + 10·0 gm. of *undried soil* = | gm. | gm. |
| Weight of crucible + *dried soil* = | gm. | gm. |
| Loss of weight = | gm. | gm. |
| Therefore, amount of water in this soil = | % | % |

Now take the crucibles containing dried soil and heat them *very strongly* over a Bunsen burner. What do you notice during heating? ..............................................

..............................................................

..............................................................

When you see no further change, allow the crucibles to cool and weigh them again.

| | *'Good' soil* | *'Poor' soil* |
|---|---|---|
| Weight of crucible + *dried soil* = | gm. | gm. |
| Weight of crucible + *burnt soil* = | gm. | gm. |
| Loss of weight = | gm. | gm. |
| Therefore, amount that burns away = | % | % |

Notice that the burnt soil is of a reddish colour in both cases, and that when the burnt soil is mixed with water it does not become sticky like the original soil. This *burnt soil* is the *mineral matter* (or *inorganic matter*) present in the original soil, while the part that burnt away was the *organic matter* present in the soil.

So far, therefore, we have found that soil has three main constituents—(*a*) *mineral matter*, (*b*) *organic matter*, and (*c*) *water*. The proportion of each constituent varies in different soils.

### PHYSICAL ANALYSIS OF SOIL PARTICLES

We can analyse the *mineral matter* still further by physical means. Take some fresh soil (about 50 gm.) and pour it into a gas-jar that is half full of water. (Make the mixture alkaline with sodium carbonate to help to keep the clay in suspension.) Close the mouth of the jar with a gas-jar cover and shake very vigorously until all the soil is suspended in the water. Then put the jar on the bench and allow the soil to settle. Notice that the soil particles settle to the bottom according to their size, the biggest and heaviest particles settling first and the smallest and lightest last. In this way, the original soil can be sorted out into its main *mineral constituents*: (i) a layer of *sand* at the bottom, then (ii) a layer of finer particles called *silt*, and then (iii) a layer of still finer particles—*clay*—on the top. (The clay particles are usually so fine that they remain suspended in the water for hours, and even for days.) Floating on the surface may be seen bits of organic matter —plant remains—which are early stages in the formation of *humus*.† Soil scientists usually classify soil particles above 2 mm. diameter as *stones*, between 2 and 0·02 mm. as *sand*, 0·02 to 0·002 mm. as *silt*, and particles of diameter less than 0·002 mm. as *clay*.

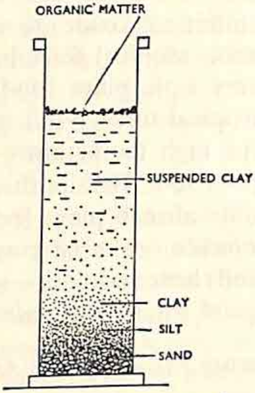


FIG. 94. Analysis of soil particles.

### THE MINERAL MATTER IN SOIL

All this mineral matter—sand, silt, and clay—has been formed by the weathering of rocks. For example, *granite* is a mixture of three minerals—*quartz*, *felspar*, and *mica*. *Quartz* (silicon dioxide,† or silica) is present in granite as hard, glassy crystals that are unchanged by physical weathering and remain as *sand*. *Felspar* (a complex silicate of potassium and aluminium) is present in granite as whitish crystals and is readily weathered to form *clay* (aluminium silicate),† since all potassium compounds are soluble in water. *Mica* (another complex silicate) is present in granite as silvery plates, and can be seen in river-sand formed by the weathering of granite. Mica also forms clay on weathering.

The weathering of *felspar* sets free *potassium salts* that are essential to plant growth, but we have seen that, in the wet tropics, almost all the constituents of granite except iron oxide and aluminium oxide are removed by warm rain-water. Unfortunately, many tropical soils, being very 'old', are of this type and contain very little plant food. It is true that these soils support dense tropical forests, but this is largely because the heavy rainfall and the high temperature are ideal for plant growth, in spite of the poor soil. Besides this, trees are of comparatively slow growth and only absorb plant food slowly from the soil. Food-crops are of much more rapid growth and make much heavier demands on the soil; hence a soil that supports trees may be quite unable to produce good food-crops *unless plant food is added to the soil.*

### SOME PROPERTIES OF SAND AND CLAY

The relative proportions of the three main soil fractions—sand, silt, and clay—vary in different soils, according to the kind of rock from which the soil was formed and the method of weathering. If a soil is mostly coarse particles, it is described as a *sandy soil*; if it is mostly very fine particles it is called a *clay soil*. If the proportions of sand and clay are roughly about the same, the soil is called a *loam*.†

Particles of sand are big enough to be seen by the unaided eye, and even when closely packed they include large air-spaces. Individual particles of clay and humus are very much smaller; in a thin watery suspension some of them can be seen with the highest magnification of the microscope, when they are observed to be in constant jerky* 'Brownian' movement, i.e. they are small enough to be moved when neighbouring molecules hit them. Such small particles can be packed very closely together, leaving only tiny air channels between them. Moreover, they have the power of '*adsorb-*

*ing*'† water, which sticks to their *surfaces* and causes the particles to swell. Under such conditions a layer of clay becomes quite water-tight and air-tight. In fact, such layers of clay are used to hold water in reservoirs. Fortunately, natural layers (or 'clay pans') of this type are rare in soils, and clay particles often stick together to form quite large groups, or 'crumbs', with large air-spaces between them.

Completely fill two short test-tubes with (*a*) dry sand, and (*b*) dry (but not baked) clay. Place each tube carefully upright with its open end under water. Notice that the dry clay takes up water and swells (like gelatine*) and expands over the edge of the tube.

## SOIL STRUCTURE

You will see from what has been said about clay that mechanical analysis alone is not enough to tell us everything about the physical properties of a soil. When a scientist begins to study a complicated thing like soil or protoplasm, his first step is often to take it to pieces and study its individual parts. He finds out a great deal in this way, but he soon finds that he must work out a method for studying the thing *as a whole*. Protoplasm is not simply a mixture of the chemical compounds it contains, nor is soil simply a mixture of sand, silt, and clay. Soil owes many of its valuable properties not merely to its composition but also to its *natural structure*. By this we mean (roughly) the degree to which the various particles are bound together into larger units or 'crumbs'. Thus some soils, though rich in clay, have a good 'crumb' structure and are easy to work when properly cultivated. This crumb structure of a soil is something that develops slowly; it is easily destroyed and it cannot easily be restored. A farmer or gardener has to learn how to preserve natural soil structure while cultivating his land and making seed-beds.

## AIR IN THE SOIL

Soil is not a closely packed solid, like rock, but it is crumbly and porous, consisting of millions of separate soil 'crumbs' with tiny spaces in between them. This '*pore-space*' in the soil is occupied by air or water (see Fig. 95). It is clear that a good soil must contain *air* as well as water so that the roots of the plants may breathe. The following experiment shows the presence of air in soil:—Take two 100 c.cm. measuring cylinders and put 50 c.cm. of water in each. Take (*a*) some dried garden soil, and (*b*) some garden soil in its normal damp condition, and measure out 50 c.cm. of each in a dry measuring cylinder, packing the soil by tapping the bottom of the cylinder on your hand. Put each measured quantity of soil into the 50 c.cm. of water, mix thoroughly by shaking, and find the volume of the mixture in each case. If the soil contained no air, then the volume of the mixture would be 100 c.cm. It is clear that any decrease in the total volume represents the volume of air in the soil.

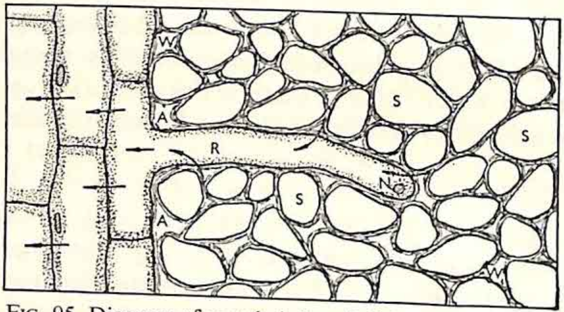


FIG. 95. Diagram of root-hair in soil (highly magnified).
S = soil particles. W = films of water. A = air spaces. R = root-hair with nucleus N.
The arrows show the path of the absorbed water.

Volume of mixture of 50 c.cm. of water and 50 c.cm. of dried soil = ............c.cm.

Therefore, volume of air in 50 c.cm. of *dried soil* = 100−........ = ............c.cm. = ............% of air, by volume.

Volume of mixture of 50 c.cm. of water and 50 c.cm. of damp soil = ............c.cm.

Therefore, volume of air in 50 c.cm. of *damp soil* = 100−........ = ............c.cm. = ............% of air, by volume.

The air in soils allows the living animals, bacteria, and plant roots to obtain the oxygen that they use in respiration. Some plant roots need very little oxygen, or they can obtain it fast enough by diffusion downwards from the stems, through internal air channels. Such plants grow well even in swamps,* e.g. the Mangrove grows in the airless mud of tidal river-banks and gets its oxygen through special 'breathing' roots, which stick up out of the mud into the air at low tide. Most normal plant roots and soil-animals, however, soon die if the soil is saturated with water. Soil structure is to a large extent maintained and the soil kept stirred and ventilated* by the continual tunnelling* of earth-worms and other small creatures, by roots growing through it, and by the changes brought about by heat and water.

### WATER IN THE SOIL

When a limited amount of rain-water falls on soil it fills most of the pore-spaces and moves downwards under its own weight until the upper layers of soil reach what is known as 'field moisture capacity'†, when downward movement practically stops. The depth to which the water moves, and hence the amount of water in the soil at 'field moisture capacity', varies with the nature of the soil, e.g. whether it is a sandy or a clay soil. We can express this in another way by saying that different soils have different *water-holding capacities*. The older experiment to show this is to pour water through columns of soils. These are then allowed to drain and the water retained* by the soil is measured. The figures thus obtained, however, although they differ for different soils, are not the same as those obtained when deep layers of soil drain naturally. A better measure of 'field moisture capacity' is given either by sampling soils for water content soon after rain, or by the following modification of the older experiment:

Take equal quantities of (*a*) sandy soil, (*b*) clay soil, and (*c*) loam, which have been spread out to dry in the sun for a few days. Take three large glass funnels, whose stems are loosely plugged* with cotton-wool, and half fill each with one of the air-dried soil samples. Weigh each funnel with its soil sample. Now saturate the soil in each funnel with water, comparing the time taken for water to come through each kind of soil. Then attach the rubber tube from a suction-pump to each funnel in turn and suck out all the water you can. (This suction replaces natural drainage.) Now weigh the funnels again and compare the water-holding capacity of sandy, loamy, and clay soils.

This experiment will show you:

(1) that water runs through sandy soils faster than through clay soils;

(2) that clay soils have a greater water-retaining capacity than sandy soils; i.e. the water content at 'field moisture capacity' is greater when there is more clay in the soil;

(3) loamy soils have properties intermediate* between those of sandy soils and clay soils.

### WATER MOVEMENT IN SOILS

It was formerly believed that water moves readily in soils at all times, passing along the very narrow capillary tubes that join the air-spaces in the soil.

It is true that water moves readily along very narrow capillary tubes *when these have one end in water*. But we know that water in glass capillary tubes does not move easily when *both* ends of the water column are in contact with air (see p. 59 and Fig. 18C). In soils that are wet to 'field moisture capacity', water does not move *downwards* unless more water is added from above (e.g. as rain). It does not move *upwards* unless there is free water below, and even then it can move only to a height of 3 feet or so, even in clay soils with fine capillaries. 'Water cannot move into dry soil if such movement would mean the drying-out of the soil behind.' It is only water in excess of the 'field moisture capacity' that moves readily in soils, and this moves *downwards*.

There are very few soils in which a free 'water table'† exists for long periods at a depth of less than 3 feet below the soil surface; hence, contrary* to older ideas, *upward movement of water in soils* *by capillarity is of relatively small importance except in irrigation* areas*. Hence we must modify the older experiment showing the upward rise of soil-water *in tubes standing in water:*

Close the lower end of a long glass tube (3 ft. long × 1 in. in diameter) with a piece of cotton cloth and pack it carefully with air-dried loamy soil. Dip the lower end of the tube into a dish of water and notice the capillary rise from this artificial 'water table'. The rise of water is shown by a darkening of the soil. When the water has risen half-way up the tube, remove the vessel of water, clamp the tube in a vertical position, and examine it at intervals. How far does the water move (now that its bottom end is not dipping into water) during (*a*) the next hour, (*b*) the next day, (*c*) the next few weeks?

In general, once the soil has dried to 'field moisture capacity' (or lower), water movement stops and plant roots have to grow from the drier soil in which they are living to the surrounding moister soil. *The roots grow towards the water and the water does not move towards the roots* once the free 'water table' is more than about 3 feet below the surface.

## CULTIVATION

In order that a soil may produce good crops, it is necessary to *cultivate* it. One object of cultivation is to prevent the soil from becoming too closely packed and too wet. This is done (*a*) by digging or ploughing, and (*b*) by drainage. Digging or ploughing loosens the soil and makes it more porous, so that air can enter easily. If the soil contains too much water, it has to be drained. The simplest method of drainage is to cut channels leading to open drains so that the excess water can run away to lower ground. A more expensive method, mainly used in temperate countries, is to lay drain-pipes of porous earthenware at a suitable depth to carry away excess water. In flat, low-lying ground, the water cannot be drained off in this way, and the only simple way of overcoming the difficulty is to grow the crop in raised beds or on ridges* of soil so that the excess water collects in the furrows between the ridges.

Govt. of West Bengal

Wet, 'heavy', clay soils can be improved by adding *lime* to them. The following simple experiment shows the action of lime on clay:—Make a suspension of clay in water and nearly fill two test-tubes with this cloudy liquid. Add a few c.cm. of *lime-water* to one test-tube and notice how the clay settles to the bottom after an hour or so, while the liquid in the other test-tube remains cloudy for several days. The addition of lime to a clay soil makes the clay particles cling together in larger grains or crumbs, so that the soil becomes more porous and air and water can pass through it more readily. Good drainage also reduces soil acidity.

Under some conditions, the soil may become too dry and it may be necessary to prevent excessive evaporation from the soil if crops are to survive. In regions of low rainfall farmers break up the surface layer of the soil, with a hoe,* to destroy weeds that would rob the soil of precious water (and plant food) needed for the crops. Evaporation can also be reduced by spreading dead grass or leaves on the surface of the soil around the crop plants, forming a '*leaf-mulch*',† which keeps the soil cooler.

### SOIL EROSION

During heavy rainstorms the rain may fall more rapidly than it can be absorbed by the soil. On flat land this causes flooding, but on sloping ground the excess water runs down over the surface, carrying with it some of the fertile top-soil. In some parts of the tropics an acre of hilly cultivated land may lose 100 tons of soil per year in this way. Soil erosion† is a most serious danger to tropical agriculture and several methods are used to control it, e.g.

(*a*) by planting trees or preserving existing forests on steep hillsides; forests also slow down the run-off, thus making streams flow more uniformly throughout the year;

(*b*) by planting rows of crop-plants *along the contour*,* rather than in rows up and down the slope, and by carrying out all ploughing and cultivation horizontally along the contour-lines;

(*c*) by making *terraces** or *contour-drains*† along cultivated slopes. Contour drains are furrows and ridges carefully laid out to follow contour-lines, and, during heavy rain, surface-water collects in these horizontal channels and sinks into the soil instead of running rapidly down the hillside, carrying valuable top-soil with it.

## TOP-SOIL AND SUB-SOIL—ORGANIC MATTER IN THE SOIL

In most countries the *surface soil* or top-soil is darker in colour than the *sub-soil*† that lies below it. This is because the surface soil usually contains decaying organic matter (the remains of plants and animals) which later becomes *humus*. One aim of cultivation is to deepen this surface layer of top-soil and keep it in the best possible condition for the growth of plants.

In some tropical soils, however, there is no visible difference between the top-soil and the sub-soil, because the soil lacks *humus*. This is due to the high temperature of the surface layer after the shady natural vegetation has been removed. It has been found that organic matter can only accumulate* in the soil as humus when the soil temperature is below 25 degrees C. (= 77 degrees F.) and that, at higher temperatures than this, humus decomposes faster than it is formed. In equatorial forests, the soil temperature seldom rises above 25 degrees C., so that some accumulation of humus can take place under forest conditions; but even here the top-soil is often only a few inches deep. When the dense shade of the natural vegetation is removed, however, the soil temperature may rise above 25 degrees C. and there can be no permanent accumulation of humus. This is the cause of one of the main problems of tropical agriculture—*how to keep a sufficient supply of organic matter in the soil*. We shall study ways of doing this later in this chapter.

## COVER CROPS

One way of reducing the loss of organic matter from the soil is to reduce the soil temperature by providing shade. We have seen that in the deep shade of tropical forests, humus gradually accumulates, but when land is cleared for agriculture, most of the natural vegetation is removed and the soil is exposed to the sun. If a quickly-growing, creeping plant is used as a *cover crop* in new clearings, the soil is shaded from direct sunlight and kept at a lower temperature, thus reducing the loss of organic matter and the loss of water from the soil by evaporation. At the same time, the leaves of the cover crop break the force of the rain while the roots bind the soil together, thus preventing soil erosion. Besides this, a creeping cover-plant of vigorous growth will control weeds, while the continual decay of dead parts of the cover-plant will add humus to the soil.

## WHAT DOES THE PLANT GET FROM THE SOIL?

When any fresh plant material is gently heated (at about 100 degrees C.), it loses at least 75 per cent. of its weight owing to the evaporation of *water*. This water, we know, came from the soil.

If the dried plant material is put in a *closed* crucible and heated more strongly over a Bunsen flame, it loses about half its weight and forms a charred mass that is mainly *carbon*. This carbon, we know, came from the carbon dioxide of the air.

If the lid is taken off the crucible so that air can enter freely, all the carbon burns away on further heating, and a little grey *ash* is left behind in the crucible; thus, wood yields about 1 per cent. of ash, leaves 10–15 per cent. This *plant ash*, which will not burn, represents* the *mineral matter* (or *inorganic matter*) that the plant has absorbed in solution from the soil, through its root-hairs. Chemical analysis of different kinds of plant-ash shows that it always contains compounds of the following elements: *potassium*, *calcium*, *phosphorus*, *magnesium*, *sulphur*, *iron*, *silicon*, *sodium*, *chlorine*, and *manganese*, along with small traces of several others, including copper, zinc, and boron.† These *ash elements* are not all absorbed accidentally with the soil water, but *most of them are essential to the healthy growth of plants*. We can find out which of these ash elements are essential for healthy growth by growing plants in culture† solutions (or *water-cultures*). We must bear in mind, however, that another element is driven off along with the carbon during burning, namely *nitrogen*, and this element must be included in our experiments with culture solutions.

## CULTURE SOLUTIONS FOR PLANTS

Most plants will grow for a time even if their roots dip only into distilled water; this is because their seeds contain the essential chemical elements in small amounts. Their growth is poor, however, and they do not flower and fruit unless we dissolve in the water small quantities of certain mineral salts. These must be so chosen as to supply the elements *potassium*, *calcium*, *iron*, *magnesium*, *phosphorus*, *sulphur*, and *nitrogen*. Two other elements are supplied by the water itself—*hydrogen* and *oxygen*—and we know that *carbon*, from carbon dioxide in the air, is absorbed by the leaves of the plant. These are the ten elements that must be supplied. If one or more is lacking, growth is slow and, after a time, when the mineral salts present in the seed have been used up, the plant fails to develop normally. A simple culture solution that supplies all these elements (except carbon) in a suitable form is: calcium nitrate, 1·3 gm.; potassium hydrogen phosphate,† 2·4 gm.; magnesium sulphate, 3·7 gm.; ferric chloride† (very little); water, 1 litre.

Experiments may be carried out by replacing one of the above salts by another from which one of the essential elements is absent; e.g. calcium sulphate may be used instead of calcium nitrate, thus leaving out nitrogen. If *iron* and *magnesium* are left out, the plants cannot become fully green, so that they are unable to make *carbohydrates* in their leaves. When *nitrogen*, *phosphorus*, and *sulphur* are left out the plants are unable to make *proteins*. We do not yet know for certain why *calcium* and *potassium* are essential for *growth*.

These experiments also show that most plants are not able to use the nitrogen gas in the air, but must be supplied with soluble nitrogen compounds—usually *nitrates*. One of the ten essential elements—iron—is required only in very small amounts.

Experiments during recent years have also shown that if the

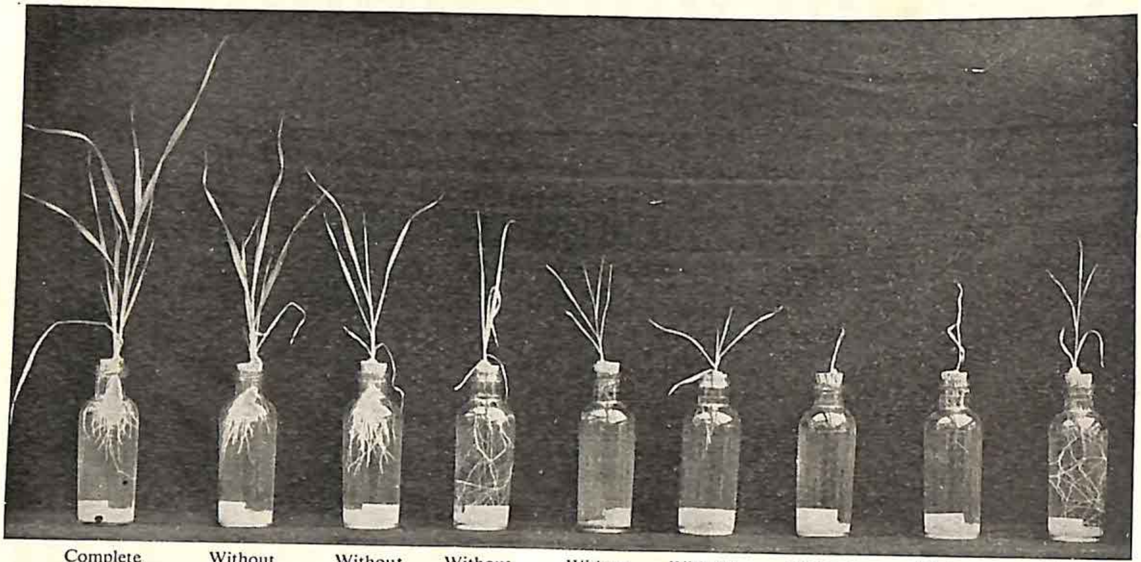


FIG. 96. Water-cultures of Barley

salts providing the above essential elements are very carefully purified, plant growth will not take place in a culture solution until very small traces (e.g. 1 part in 1 million parts of water) of some other elements are added. Besides the ten major* elements, plants also need very small traces of *manganese*, *zinc*, *boron*, and *copper*.

### PLANT FOOD IN THE SOIL

All the *essential elements*, except nitrogen, can be supplied by the weathering of rocks, and only four of them—*nitrogen*, *phosphorus*, *potassium*, and *calcium* (in that order of importance)—usually need replacing in cultivated soil.

Under natural conditions, e.g. in tropical forests, there is little danger that all the plant food in the soil will be used up, because plants die and decay, and their mineral constituents are returned to the soil to be used over again by new plants, i.e. 'Nature's chemical capital is put back into circulation'. Under such natural conditions, therefore, nearly all the soluble salts taken from the soil by plants are returned to the soil again when the plants die and decay, and any slight losses are made good by the weathering of the underlying rock. But there is one essential element—*nitrogen*—that is not replaced by weathering, because rocks contain no nitrogen compounds. Nitrogen compounds, however, are present in all living things (as *proteins*) and when the organic remains of plants (and animals) are returned to the soil, these nitrogen compounds, after undergoing suitable changes, can be used by other plants.

### MICRO-ORGANISMS IN THE SOIL

If plants and animals remained perfectly preserved after death, the 'chemical capital' they contain would be permanently locked up and would not be put back into circulation. We have seen that while animals feed on complex food-materials, manufactured in the first place by plants, it is only the simplest substances that are suitable for feeding plants—carbon dioxide, water, and a few simple inorganic salts. Hence, before the dead remains of plants and animals can become suitable for plant food, they must *decay*, i.e. *decompose into simpler substances. Decay is a process brought about by very tiny living things* (or micro-organisms)†, *the fungi*† (flowerless plants or moulds) *and the bacteria*, which are present almost everywhere, in the air (as *spores*), and in the soil.

In tropical countries, *termites*† (white ants) help these fungi and bacteria by attacking dead wood, which could only be decomposed slowly by fungi and bacteria. *Earthworms* eat their way through the soil, sucking in and swallowing soil containing particles of animal and vegetable matter, which are broken down into simpler substances in the worm's food-canal.

The *soil micro-organisms* that bring about decay are living things and therefore require food, both as a source of energy and in order to build up their own protoplasm. They use as their source of energy the carbohydrates present in plant and animal remains. They give off carbon dioxide during respiration, and build up their own bodies from the proteins. Then, if there are any proteins left over, they convert them into *ammonia*. The *soil fungi* are mainly concerned with the early stages of decay, e.g. breaking down the carbohydrate *cellulose* into simpler carbohydrates. The *soil bacteria* complete the decay, producing *ammonia* from proteins, and, finally, other *nitrate-making bacteria* convert this ammonia into *nitrates*. These colourless plants bridge the gap between green plants and animals by completing the *cycle of elements*. They feed on more complex food-substances than green plants, but on less complex food-materials than animals require.

## THE SUPPLY OF NITROGEN COMPOUNDS

We have seen that the most important element that the plant takes in from the soil is *nitrogen*, in the form of *nitrates*, and it is clear that, if this supply of nitrates is not maintained, plant growth will suffer, for without nitrates the plant cannot make *proteins*. In theory, if all the plants in a given area are returned to the soil from which they grew, after they have decayed there should be no permanent loss of plant food. In practice, however, there are losses.

For example, in soils containing too little air, other groups of *nitrogen-freeing bacteria* undo the work of the nitrate-making bacteria and convert nitrates into free uncombined nitrogen, which is useless to the plant. Besides this, some nitrates are washed out of the soil by heavy rainfall and are not replaced by weathering.

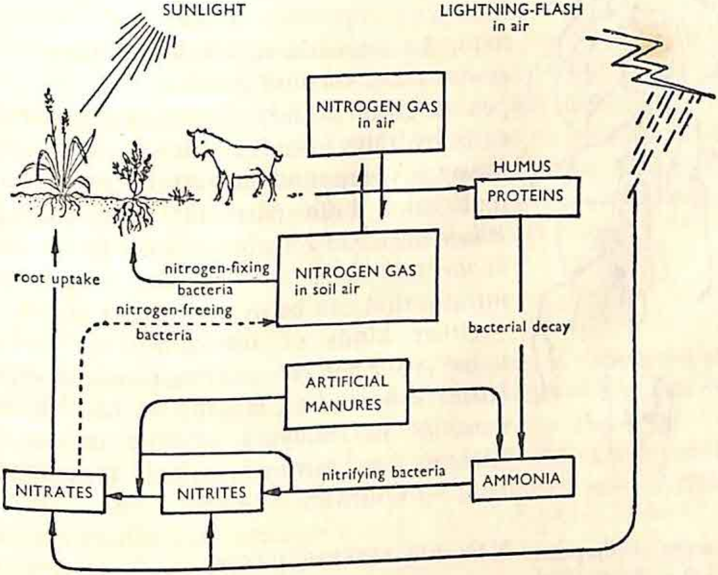


FIG. 97. The Nitrogen cycle.

Hence, unless these nitrates are replaced in some other way, the supplies of nitrogen compounds in the soil would have been exhausted* long ago. Fortunately, there are two natural sources of nitrates. In tropical countries, the rain-water contains small quantities of nitrates formed by the combination of nitrogen and oxygen in the neighbourhood of lightning† flashes during thunderstorms. It has been estimated that, in some tropical countries where thunderstorms are common, an acre of ground may receive over 50 lb. of nitrates per year in this way. In forest regions, this is sufficient to balance any losses. This source of nitrates is clearly much less important in regions where thunderstorms are rare.

The other natural source of supply of nitrates is by the action of another class of bacteria—the *nitrogen-fixing bacteria*, which can convert free nitrogen from the air into nitrogen compounds. Some of these nitrogen-fixing bacteria live in small swellings on the roots of *leguminous*† *plants* (belonging to the pea or bean family), obtaining water and carbohydrates from their 'host' and supplying nitrogen compounds in return—an exchange that helps both partners* (see Fig. 98). *When the dead remains of such plants decay in the soil*, these nitrogen compounds yield nitrates that can be used by other plants.

Other kinds of nitrogen-fixing bacteria living *in the soil* can use free nitrogen *without having a host-plant*, feeding on carbohydrate material in decaying organic matter and 'fixing' free nitrogen, which is converted later into nitrates.

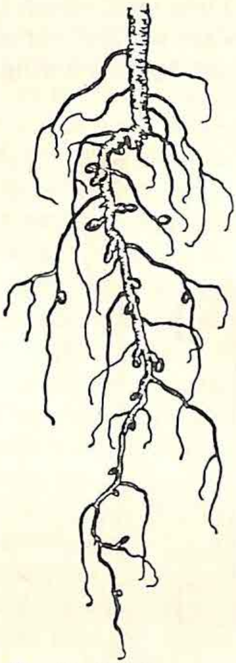


FIG. 98. Swellings on root of Cow-pea plant.

### MANURES AND FERTILIZERS

We have seen that under natural conditions, e.g. in tropical forests, where everything that grows from the soil finally returns to the same soil, the fertility of the soil is maintained and even improved. When Man interferes with Nature, however, and cultivates crops, he often removes the greater part of the plant material when he harvests the crop, thus robbing the soil of some of its food materials. If several crops are removed in this way, one after the other, without any return being made to the soil, some of the essential mineral salts will become exhausted. Hence, if the same soil is to be used year after year for cultivated crops, these mineral salts have to be replaced.

One way of replacing the essential *nitrogen*, *phosphorus*, *potassium*, and *calcium* compounds is by adding *animal manure*† to the soil. Animal manure consists of the undigested remains of the food material after the animal has absorbed the digested carbohydrates, fats, and proteins. (The carbohydrates and fats are used by the animal mainly as a source of energy, and the proteins build up its body.)

If the animal is working, or growing, or yielding milk, it will need more proteins and mineral salts for itself so the manure will be 'poorer' than in the case of an older animal kept resting in a cattle-pen.* The latter animal will pass out in its manure most of the nitrogen, potassium, phosphorus, and calcium compounds contained in its food, and such *pen-manure* contains all the necessary mineral salts, besides supplying *humus* to the soil.

## ARTIFICIAL MANURES

Although cattle-manure is the best fertilizer, it cannot be produced in sufficient quantities for the requirements of modern agriculture, and *artificial manures* (or *fertilizers*) are also used. The most suitable kinds and quantities of artificial manures for different soils have to be found by careful experiment, since different soils require different treatment.

The most important *nitrogen-containing compounds* used as fertilizers are (*a*) *ammonium sulphate* and (*b*) *sodium nitrate*, the former being cheaper and giving better results in countries with a heavy rainfall.

The most important phosphorus compounds used as fertilizers are (*a*) powdered *phosphate rock* (calcium phosphate),† (*b*) '*superphosphate*'† (made from bones and mineral phosphates by the action of sulphuric acid), and (*c*) *basic slag*† (a by-product from the manufacture of steel).

*Potassium* is supplied in the form of either potassium chloride or sulphate.

*Slaked lime*, besides providing the essential element calcium, also improves the qualities of clay soils, in addition to neutralizing the acidity of 'sour' soils.

### GREEN MANURES

*Green manures* are usually rapidly-growing plants that are dug into the soil so that they may decay and enrich the soil with *humus*. Most plants, used in this way, can only return to the soil the same essential elements that they absorbed from the soil. But we have seen that *leguminous plants* can do more than this. Because of the *nitrogen-fixing bacteria* in their root-swellings, they can convert free nitrogen from the atmosphere into nitrogen compounds. When such *leguminous green manures* are dug into the soil and then decay, they actually enrich the soil with the all-important nitrates.

### COMPOSTING

We have seen that under natural conditions, e.g. in old jungle that has not been disturbed by Man, the fertility of the soil is maintained because all the plant food taken from the soil finally returns to the soil again as the result of decay, and also because *humus* accumulates under such conditions. When Man cultivates the soil and removes crops from it, he must replace the essential mineral salts and supply sufficient humus if the soil is to remain fertile and produce further good crops. We have seen that the essential mineral salts can be supplied by using artificial fertilizers, i.e. inorganic salts, but these alone will not maintain the fertility of the soil, particularly in tropical countries. Organic manure is also necessary to supply humus. This is why cattle-manure is such an excellent fertilizer—it provides both mineral salts and humus.

A similar organic manure can be made from plant material, without passing it through an animal's food-canal, by *composting*.† In all agriculture and gardening there are large quantities of waste plant material, e.g. grass and bush cuttings, fallen leaves, and unwanted parts of crop plants. These plant remains are often burnt and their ashes used as a fertilizer. But although this plant-ash contains most of the mineral matter in the original plant material, all the organic matter and the nitrogen compounds have been lost. A much better way of using this waste material is to convert it into organic manure by the right kind of fungal and bacterial decomposition, i.e. by *composting*.

The plant remains are dried in the sun before they are added to the *compost heap* or *humus pit*.* A compost heap can be made above the ordinary ground level, or on a slope, in wet countries, or in a shallow humus pit in drier countries. The heap is usually oblong:* about 9 ft. by 6 ft. is a convenient size. A layer of dried plant material is put at the bottom, about 1 ft. thick (before it is pressed down). A thin layer of cattle manure, about 1 in. thick, is then spread on top, followed by a thin layer of soil. Any wood ashes that are at hand (from cooking fires, for example) are then dusted over the soil, and the heap is thoroughly watered. More layers of dried plant material, animal manure, soil, and wood ashes are added in the same way, and wetted thoroughly after each addition, until the heap is about 3 ft. high. The heap soon begins to get warm, until after a day or two the middle of the heap may reach a temperature of about 60 degrees C. (= 140 degrees F.). This shows that the micro-organisms of decay are very active, feeding on the manure and converting the plant remains into humus. (This high temperature also stops flies from breeding* in the compost heap.)

The compost heap must be kept damp by daily watering (in the absence of rain); but not so wet as to stop a free supply of air to the inside of the heap, for the micro-organisms that bring about this type of decay can live and multiply only in the presence of oxygen. (If the air supply is insufficient, other organisms, living in the absence of oxygen, will start a less useful type of decay, characterized by an unpleasant smell. A properly managed compost heap is not a nuisance.) A compost heap of this size contains about 500 lb. of dried plant material, 50 lb. of animal manure, and 2 lb. of wood ashes. In the absence of rain, about 4 gallons of water a day will keep the heap sufficiently damp.

For the next few weeks the temperature of the heap gradually falls until it is only a few degrees above the air temperature, showing that the micro-organisms are becoming less active owing to lack of oxygen. So the heap is turned and rebuilt, with the outer part of the old heap in the middle of the new one.

The compost heap soon gets hot once more, and decay continues for a further few weeks. The heap is re-turned and rebuilt until the final rise in temperature of the re-made compost heap is only a few degrees, showing that the bacterial decomposition is complete. This stage is usually reached after the heap has been turned three or four times, i.e. in two or three months from the start, and the final product is a soft, 'light', dark brown material —*compost*—which should be dug into the soil as soon as possible before it loses part of its value as a fertilizer owing to the action of nitrogen-freeing bacteria.

One of the main problems of tropical agriculture and gardening is how to keep sufficient organic matter in the soil. The proper use of *compost heaps* or *humus pits* is the best solution of the problem, since properly made compost can be used instead of cattle-manure.

Where cattle are kept in cattle-pens, if plenty of waste plant material is put in the pens each day, it can be taken away at frequent intervals, after becoming mixed with a little manure, and made into a compost heap outside. In this way, a little cattle manure makes a lot of good compost.

## THE ROTATION OF CROPS

Many years ago, farmers found that if they planted the same crops in the same ground, year after year, the crops they obtained became smaller and smaller; but if they grew different kinds of plants in succeeding years the results were better. This principle of having a *cycle of crops*, or of crops and pasture* plants, is called *crop rotation*† and is practised mainly in temperate climates. With tropical plantation crops, such rotation is seldom possible. For example, crops like rubber, coconuts,† tea, coffee, and cacao (cocoa), occupy the same ground for several years at a stretch and cannot be fitted into any simple rotation. Even crops like rice and sugar-cane are usually grown on the same land year after year, with occasional '*fallowing*'† (see below).

A typical three-year crop rotation usually consists of the following classes of crops:

(*a*) *Cultivated crops*, e.g. cotton, tobacco, maize, root crops (cassava, sweet potatoes, yams), or vegetables, where the ground is dug or hoed between the plants, thus killing the weeds that would survive in a grain crop where the plants are so close together that weeding is impossible. Such cultivated crops, too, are usually deep-rooted, thus taking their supply of mineral salts from the deeper layers of the soil.

(*b*) *Small grain crops*, e.g. rice, millet, wheat, barley,† or grasses for feeding cattle, which have shallow root systems and absorb their food material from the top layer of soil, left almost untouched by the deeper roots of the cultivated crop grown in the earlier season. This crop will also profit by the removal of weeds during the previous season.

(*c*) *Leguminous plants*, e.g. peas, beans, ground-nuts, grams,† or lentils.† Some of these plants are often grown as *green manure*. They are buried in the soil by digging or ploughing, and when they decay they increase the supply of humus and also enrich the soil with nitrates.

Rotation of crops and proper manuring will prevent *soil exhaustion* in temperate climates, but in most tropical countries it is impossible to supply enough manure to maintain fertility under continuous cropping with annual crops. So land used for growing short-term crops is usually '*fallowed*', i.e. given a rest from growing crops, every few years. For example, after growing annual crops for three years, the land is sometimes allowed to grow grass for the next three years so that the fibrous grass roots will improve the soil structure and thus help to restore its fertility. This is a modification of the primitive* and wasteful system of '*shifting cultivation*'†, still common in some tropical countries, in which forest land is cleared and food crops are grown for a few years until the soil is exhausted. The clearing is then allowed to return to 'bush' or forest while the cultivator clears a fresh patch. It is clearly less wasteful of land if the first clearing is rested as a '*grass fallow*' that can be grazed* by cattle for a few years and then *used again* for food crops.

Crop rotations are also useful for starving out *plant diseases* and *harmful insects*. Most plant diseases and harmful insects attack only one particular kind of crop plant. For example, related plants like tomatoes and English potatoes are attacked by similar fungus diseases, but these diseases will not attack plants belonging to another plant family. Hence, if a crop is being attacked by a plant disease or a harmful insect, it is a good plan to replace it next season by a different crop that is not attacked by the same enemies.

To sum up, therefore, a good *crop rotation* has the following advantages:

(i) *It removes the mineral constituents of plant food evenly from all parts of the soil.*

(ii) *It helps to control weeds.*

(iii) *It improves the condition of the soil.*

(iv) *It starves out harmful insects and plant diseases.*

Learning Exercises on Chapter VI will be found on pp. 53–57 of *General Science Workbook I.*

## CHAPTER VII

# SOUND

### HOW TO SHOW THAT SOUND IS CAUSED BY MOVEMENT

(i) Strike a *tuning-fork*† against the knee-cap so that it produces a sound. Just touch the surface of some water with the end of one arm of the sounding fork.

What happens? ..............................

..............................

Why? ..............................

..............................

(ii) Hang up a ping-pong† ball by a thin thread. Gently touch the ball with the end of one arm of a sounding tuning-fork.

What happens? ..............................

..............................

Why? ..............................

..............................

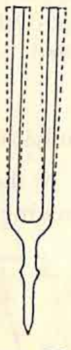


FIG. 99. Vibrations of tuning-fork.

(iii) Stretch a thin string or wire on a *sonometer*† as shown in Fig. 100. Pull the string to one side and then let go so that it produces a sound. Notice that the middle of the string looks broader when it is sounding than when it is at rest. While the string is sounding, gently drop a 'rider' of folded paper across the string.

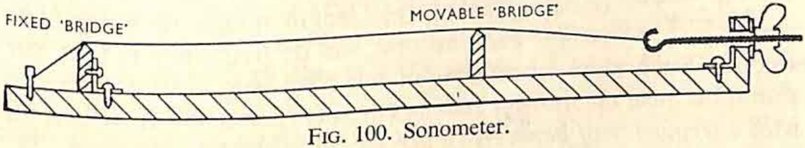


FIG. 100. Sonometer.

What happens? ......................................

......................................................

Why? ..............................................

......................................................

These simple experiments show that when something is producing sound it is moving rapidly. *Sound is the result of moving matter —without a movement there can be no sound.* If we touch a tuning-fork while it is sounding, we stop its movement, and the sound stops at the same instant. All everyday sounds are connected with movement, e.g. the rapidly-moving wings of a mosquito produce a sound; when a drum is struck, the drum-skin moves rapidly backwards and forwards and produces a sound.

VIBRATION

In the above experiments, the things that produced sounds were moving rapidly backwards and forwards—or *vibrating.*† The simplest example of slow vibration is a simple *pendulum,*† a small, heavy ball swinging from side to side on the end of a thin thread (see Fig. 101). Each complete swing of the pendulum, *there and back*, is called a *vibration* or *cycle*. The longer the thread of a pendulum, the slower are its vibrations. For example, a 25-cm. pendulum makes two complete swings each second and we say that its *frequency*† is two vibrations per second. A pendulum one-quarter of this length makes four complete swings each second, i.e. its frequency is four per second. Such slow vibrations, of *low frequency*, do not produce sound because *the average human ear is only sensitive to vibrations with a frequency of between* 16 *per sec. and* 20,000 *per sec.*

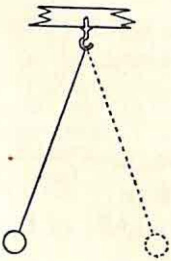


FIG. 101. Simple pendulum.

A wooden metre rule, or a hack-saw* blade, with one end held firmly in a clamp, can also be made to vibrate backwards and forwards, but the frequency of the vibrations is usually too low to produce a sound.

Adjust a gramophone† motor to its fastest speed (usually between 100 and 120 revolutions* per minute) and then count the number of revolutions per minute, using a seconds clock. Place a circular piece of paper (of about 12 in. diameter, with a hole at its centre) on the turn-table. With a piece of soft wax, attach a very fine brush (or a piece of pencil lead) to the end of one arm of a large tuning-fork, and ink the brush. Set the turn-table in motion, and when it is revolving at a steady speed, strike the tuning-fork (with a rubber cork on the end of a thin stick), and quickly hold the brush in contact with the moving paper. The vibrating brush traces out a wavy line on the paper. Lift up the brush before the turn-table completes a whole revolution. Repeat this several times, then stop the motor and remove the paper (see Fig. 102).

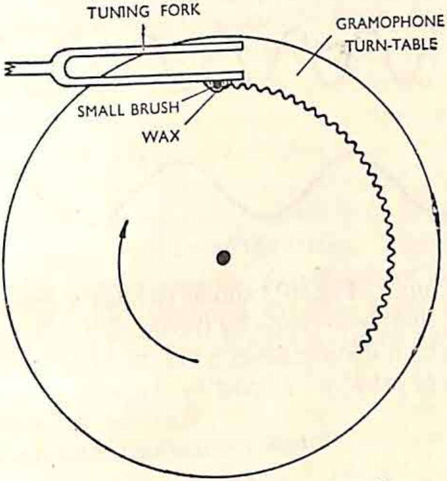


FIG. 102. Wave trace of tuning-fork.

Pick out your best wave-trace and fold the paper exactly into four (like a filter-paper), then open it out and count the *complete waves*, or vibrations, in one-quarter of a revolution.

Number of revolutions per minute ........
Number of complete waves in 90° on paper ........
Therefore, number of vibrations per minute = ...... ×4× ......
= ........
Therefore, number of vibrations per second = ........ ÷ 60
Therefore, *frequency of tuning-fork* = ........ per second.

Repeat this experiment with another, smaller tuning-fork that gives a 'higher' note. Fig. 103 shows two wave-traces made in this way. Which of them was made by the larger tuning-fork? *Musical pitch*† is that which distinguishes a 'high' note from a 'low' note, and *differences in pitch are caused by differences in frequency.*

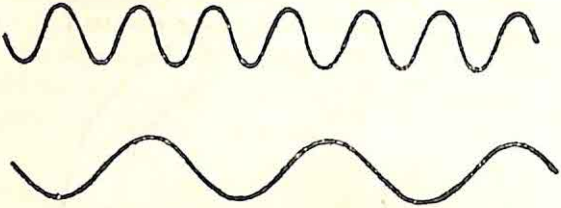


FIG. 103. Wave traces.

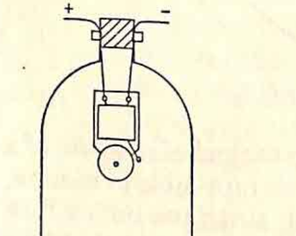


FIG. 104. Bell ringing in a vacuum.

HOW DOES SOUND TRAVEL?

(*a*) *How to show that sound cannot travel through a vacuum, but that it can travel through air.*

If an electric bell is placed inside a bell-jar connected to an air-pump, as shown in Fig. 104, the sound of the bell gets weaker and weaker as the air is pumped out. If the pump is efficient and removes practically all the air from inside the bell-jar, the sound dies away almost completely,[1] although the hammer of the bell can still be *seen* vibrating. When air is let into the bell-jar again, the sound gets louder and louder. Hence, *sound cannot pass through a vacuum, it can only be transmitted through matter.* Although sound usually travels through the air to reach our ears, air is not the only material through which sound can travel; it can travel through any solid, liquid, or gas.

---

[1] A faint sound may be transmitted along the wires connected to the bell.

(*b*) *How to show that sound can travel through solids.*

(i) Hold one end of a long wooden rod firmly against your ear while someone holds a clock or watch in contact with the other end.

What happens? ..............................................

..............................................................

Why? ....................................................

..............................................................

(ii) Take a piece of strong string about 3 ft. long and tie one end of an iron bar to the middle of the string. Wrap the free ends of the string several times round the fore-finger of each hand and then press the tip of each fore-finger on your ears. With the iron bar hanging freely by the string, allow it to strike a chair.

What happens? ..............................................

..............................................................

Why? ....................................................

..............................................................

(iii) Hold one ear against the end of a long iron railing* (at least 100 ft. long), and listen while someone strikes the other end of the railing with a hammer.

What happens? ..............................................

..............................................................

Why? ....................................................

(iv) Take a long piece of string (about 100 ft.) and thread each end through a small hole bored in the bottom plate of a cylindrical tin can (e.g. a cigarette tin). Tie a knot in each end so that when the string is pulled tight the knots rest against the inner sides of the holes. Now get a friend to speak into one of the tins while you place your ear at the other, the string between them being kept straight and tight. Does sound travel along the string? Repeat the experiment with the string hanging loosely. Notice that when the string is pulled hard against the bottom plate of the can this *makes the sound louder* at the receiving end.

(*c*) *To show that sound can travel through liquids.*

It is not so easy to show that sound travels through liquids, because in the laboratory the liquid has to be in a solid vessel, and sound travels through the solid as well as through the liquid. But you can hear sounds that have travelled through water the next time that you swim under water or float with your ears under water.

## THE SPEED OF SOUND

It is clear that sound travels much more slowly than light, because during distant thunderstorms the lightning is seen long before the thunder that it causes is heard. Similarly, the puff* of steam from a distant steam whistle is seen long before its note is heard, and we see a rocket* burst in the sky before we hear the explosion.

The speed of sound in air can be found by measuring the time between the flash and the sound of a distant gun. In an early experiment, two big guns were placed a measured distance apart* (about 11 miles): one gun was fired and the observer at the other gun timed the interval between the flash and the sound. The other gun was then fired and an observer at the first gun timed the interval between the flash and the sound. If any wind was blowing, it helped one sound and hindered the other, so the speed of sound in still air could be calculated. In dry air at 0 degrees C., the speed of sound is 1,087 ft. per sec., and it increases by about 2 ft. per sec. for every Centigrade degree rise of temperature. At 30 degrees C. (= 86 degrees F.) in dry air, sound travels with a speed of 1,147 ft. per sec., but in damp air sound travels a little faster than in dry air. For everyday purposes, *the speed of sound in damp air near sea level in the tropics is about 1,150 feet per second.* This is about 785 miles per *hour*, or about *one-fifth of a mile per second*; quite slow when compared with the speed of *light*, which is 186,000 miles per second (i.e. about a million times faster than sound).

The next time there is a thunderstorm, make use of the fact that sound travels about 1 mile in 5 seconds, to find how far away the lightning is. As soon as you see a lightning-flash, start counting seconds, 'And one, and two, and . . .', until you hear the thunder.

In ships at sea the distance from a lighthouse can be determined if the lighthouse sends out a flash of light or a wireless signal and a sharp sound at the same instant. Thus, if an observer on a ship counts an interval of 17·5 seconds between seeing the flash and hearing the sound, how far is the ship from the lighthouse?......
.................................................

In water, sound travels nearly five times faster than in air. In earth or rock, sound travels about twenty times faster than in air.

## WAVES

To understand how sound travels from a vibrating object to the ear, it is necessary to know something about *wave motion.*

(i) (*Demonstration.*) Hang a long spring vertically and fasten a weight to its lower end. Pull down the weight through a short distance and then let it go. Notice the 'to-and-fro' waves of alternate compression and extension running up and down the spring. These 'to-and-fro' waves (sometimes called 'push-and-pull' waves or *longitudinal waves*) illustrate the kind of wave motion by which sound travels through the air. *Alternate waves of compression and expansion travel outwards in all directions from the source of a sound* (see Fig. 107).

(ii) A clear picture of this type of wave motion can be seen by watching the walking movements of a large *millipede*,† especially when the animal is viewed against the light (see Fig. 105). When the animal is at rest, its legs are all evenly spaced. As it begins to walk its legs become grouped in zones*—there is a zone in which the legs are close together next to a zone in which they are wider apart. These alternate zones of 'compression' and 'expansion' move forward continually as the animal walks, and a *longitudinal wave* of movement runs forward from tail to head.

(iii) Nearly fill the sink or a large trough with water, and, when the water is quite still, arrange a burette with its jet a few inches above

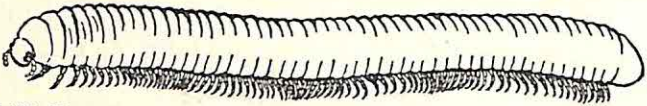


FIG. 105. Walking movements of millipede. (Showing alternate zones of 'compression' and 'expansion'.)

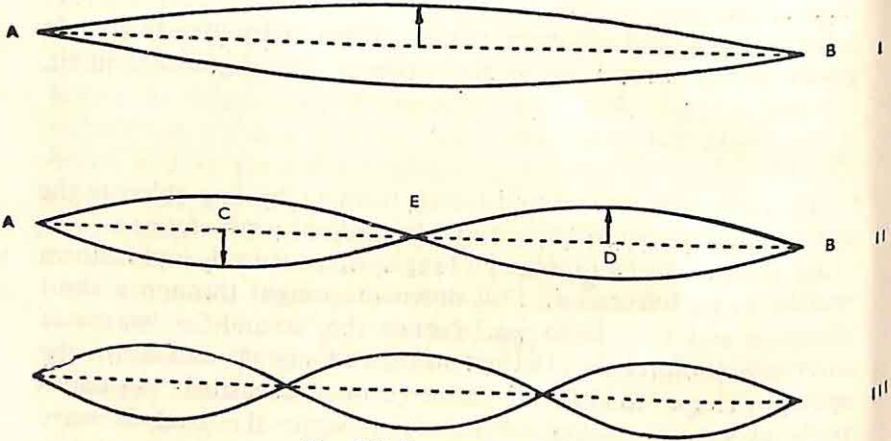


FIG. 106. Transverse waves.

the surface of the water and dripping water at the rate of about one drop per second. Notice how a circular *wave* travels outwards from the centre of the disturbance. A *sound-wave* travels outwards from the source of sound in much the same way.

Now put a few bits of wood or cork on the surface of the water and repeat the experiment. Notice that the floating material does not travel outwards with the waves, but only moves up and down. This gives some idea of how sound travels in air, waves of sound travelling outwards from the source in all directions, *although the air itself does not flow outwards.*

(iv) (*Demonstration.*) The up and down movement of water particles as a wave travels through the surface can be imitated with a rubber tube, at least 10 ft. long, filled with sand. One end is fastened to a wall and the other end is pulled tight with the hand. A sudden shake with the hand sends an up and down wave along the rubber to the wall. Notice that, although a wave runs along the rubber, the grains of sand simply move up and down (see Fig. 106).

These two experiments illustrate what is meant by an '*up and down wave*', usually called a *transverse*† (*crossing*) *wave.* Such waves in vibrating solids often set up sound waves in the surrounding air.

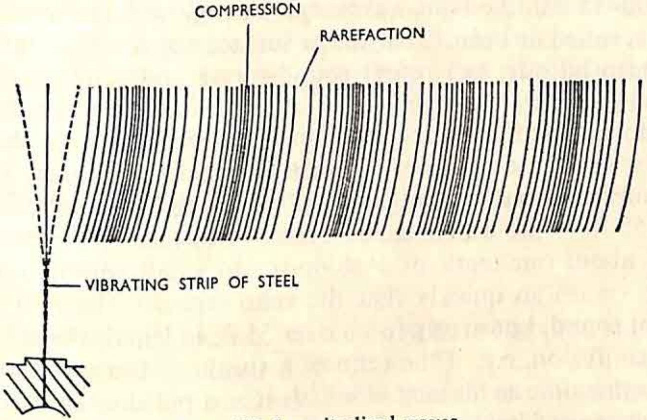


FIG. 107. Longitudinal waves.

SOUND-WAVES

Consider a vibrating strip of steel, e.g. a hack-saw blade with one end held firmly in a clamp (see Fig. 107). As the steel swings from left to right, it pushes the air molecules in front of it, crowding them together and slightly compressing the air. But owing to 'the spring of the air' this compressed air at once expands again and hits the next layer of air lying in front of it and compresses it in turn; and so on. In this way, a series of compression-waves is formed, travelling outwards from the vibrating strip of steel. As the steel swings back from right to left, the pressure on the neighbouring air is reduced, so that a wave of expansion (or *rarefaction*†) follows every wave of compression. In this way, a vibrating object sets up a cycle of alternate compressions and rarefactions travelling outwards through the air. When these waves reach the ear-drum, it vibrates at the same frequency, and if this is between about 16 and 20,000 per sec., the nerves of hearing carry the sensation* of sound to the brain. Your teacher will show you how to make a 'Crova's Disc',† which enables you to see very clearly this succession of waves of compression and rarefaction travelling outwards.

## THE REFLECTION OF SOUND—ECHOES

Sound-waves, like light-waves, can be *reflected*, and a reflected sound is called an *echo*.† Any large surface, e.g. a wall, a building, or a steep hillside, can reflect sound-waves and produce echoes. The human ear, however, can only distinguish between two separate sounds if they are more than 0·1 sec. apart, so that one must be at least 55 ft. away from a wall before the echo can be distinguished from the original sound (so that the sound-waves travel 55 ft. *to* the wall and 55 ft. *back* to the ear—110 ft. in all—taking about one-tenth of a second). In small rooms, reflected sounds return so quickly that the echo seems to be part of the original sound, but in any room over 55 ft. in length the echo may cause confusion, e.g. if the echo of a speaker's last word is heard at the same time as his next word. Just as a polished surface is the best reflector of *light*, smooth, hard surfaces are the best reflectors of sound. Hence, in order to reduce troublesome echoes in large rooms, e.g. cinemas,* the walls are covered with soft, thick, porous materials to absorb the energy of the vibrating air molecules and thus reduce the loudness of the reflected sound.

## DEPTH SOUNDING BY ECHOES

In ships and aeroplanes use has been made of the principle of *echoes* in taking *soundings*.* Aeroplanes carry aneroid barometers (*altimeters*) to show their height, but such an instrument gives only the vertical height above the ground at the starting-point. When the weather is misty or cloudy, an aeroplane may be approaching mountainous country and, although the altimeter reads several thousand feet, the aeroplane may be quite close to this high ground and in danger of a crash.

A simple method of '*sounding*' that can be used in an emergency* is as follows: A shot is fired from the aeroplane and the time taken for the sound to travel to the ground and back is measured; the aeroplane's height *above the ground beneath it* can then be found. For example, since sound travels at about 1,150 feet per second in air, if the echo is heard 1 sec. after the shot is fired, the ground is about 575 ft. below.

A similar method has been used on ships. A suitable sound is produced beneath the surface of the water, and the time is taken until the sound-wave returns to the ship after reflection from the bottom of the sea, i.e. until the echo is heard. For example, since sound travels at about 5,000 ft. per sec. in sea-water, if the echo is heard 1 sec. after the original sound, the sea is about 2,500 ft. deep at that point. Rocks, wrecks, ice, and even masses of fish can be discovered by similar *echo-sounding* methods.

### NOISE AND MUSIC

We usually divide sounds into two classes, *noises* (or unmusical sounds) and *notes* (or musical sounds).

(i) *Noises* are rough and unpleasant sounds produced by vibrations that follow each other at irregular intervals, i.e. *noises have no definite pitch.* Thunder, the roar of a moving train, and the firing of a gun are examples of *noises.*

(ii) *Musical notes* are smooth and pleasing sounds caused by a regular succession of similar disturbances, i.e. they are produced by vibrations of regular frequency. Hence *musical notes have a definite pitch.* They differ from one another in (*a*) *pitch*, (*b*) *loudness*, and (*c*) *quality*.

The pitch of a note depends only on the number of vibrations per second, i.e. on the *frequency* of the vibrations producing the note. The greater the frequency, the higher the pitch of the note. This relation between frequency and pitch is illustrated by the siren.†

A *siren* consists of a circular disc of metal mounted on an axle so that it can be turned very rapidly. A circle of regularly spaced holes is bored through the disc, and a jet of air is directed against the ring of holes as the disc revolves (see Fig. 108). Whenever a hole comes opposite the air-jet, a puff of air passes through; so that, as the disc revolves, puffs of air follow each other rapidly and *at regular intervals*, thus producing a musical note. The frequency of the note is the number of holes in the disc multiplied by the number of revolutions per second. Notice that as the speed of the disc increases, the *frequency* of the puffs of air increases and the *pitch of the note rises*. A similar result is obtained if a strip of thin cardboard is held against a revolving toothed wheel. As the speed of revolution increases, the vibrating card gives out a note of rising pitch.

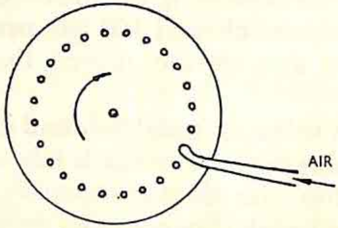


FIG. 108. Simple siren.

The *loudness* of a note depends on *the extent of the vibrations* of the sounding object, e.g. the farther a stretched string is pulled aside before being let go, the greater the extent of its vibrations and the louder its note. This is because more energy is given to the air in the form of more marked waves of compression and rarefaction, and these waves pass on more energy to the eardrum.

If the same note is produced with equal loudness from two different musical instruments, e.g. a piano† and a flute,† although the pitch and the loudness are the same, the notes differ in *musical quality*. This difference is due to differences in the character of the two sound-waves caused by the complex nature of the vibrations produced by musical instruments.

### RESONANCE

*Resonance*† (or *co-vibration*†) is the process in which a vibrating object passes on its own vibrations to another object that has the same natural vibration-frequency as itself. Air columns in tubes, stretched strings, and anything that is able to vibrate, all have their own natural frequency of vibration.

The principle of resonance can be demonstrated by the following experiments:

(i) Fix a tuning-fork A to a *sounding-box*† (see Fig. 109). Strike on your knee-cap another tuning-fork B, *of the same frequency as* A, to make it vibrate, and hold its stem on the sounding box for a short time. Then remove B and stop it vibrating. Notice that the fork A is now vibrating and giving out the same note as did B.

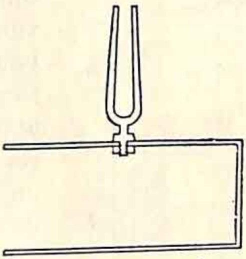


FIG. 109. Sounding-box.

(ii) Hold a simple pendulum, about 25 cm. long, in your hand and set it swinging by moving your hand backwards and forwards with different frequencies. Find the frequency that gives the widest swings of the pendulum with the smallest movement of your hand. You will find that you get the widest swings with the smallest effort when your hand-movements have the same frequency as the natural frequency of the pendulum. A 25-cm. pendulum, for example, swings twice per second when hanging from a fixed support. If the to-and-fro movements of your hand are '*in step*' with the vibrations of the pendulum, then very small forces will make the pendulum swing much farther from side to side. In the same way you must time your pushes properly if you want to keep a child's 'swing' moving to and fro.

(iii) Take a wide glass tube, standing in a tall jar of water, as shown in Fig. 110. Sound a tuning-fork near the mouth of the tube and move the tube slowly up and down until the sound becomes loudest. Clamp the tube in this position. The tuning-fork and the column of air inside the tube are now said to be *in* *resonance* with each other. Blow across the mouth of the glass tube and notice that it gives the same note as that given by your tuning-fork, i.e. the vibrations of the tuning-fork are '*in step*' with the natural frequency of vibration of the air column. Repeat the experiment with tuning-forks of different frequencies and adjust the length of the air column to resonance. Notice that the shorter the air column, the higher is its frequency of vibration and the higher is the pitch of the note produced.

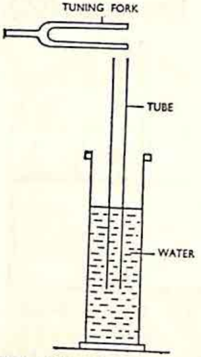


FIG. 110. Resonance.

In general, any object that can vibrate with some particular frequency can be made to vibrate actively by the vibrations of a neighbouring body, *if these vibrations are of the same frequency*, or 'in step'. This principle of resonance, or co-vibration, is very important in wireless signalling. A wireless receiver is 'tuned' until its *electrical* vibrations are in step with those produced by the broadcasting transmitter. In this way we can separate the different 'stations' transmitting wireless waves of different frequency.

Tuning-forks are often mounted on thin wooden boxes, open at one end, of such a size that the air column inside the box vibrates 'in step' with the fork and so gives a much louder note. These boxes are called '*sounding-boxes*' or *resonance-boxes* (see Fig. 109). The same principle is applied in many musical instruments.

## VIBRATING STRINGS

When a string or wire, stretched between two fixed supports, is pulled to one side and then let go, *transverse vibrations* are set up in the string and these produce longitudinal waves in the surrounding air. If these are sufficiently rapid (more than 16 per sec.), a musical note is produced. This principle is the basis of all stringed musical instruments, e.g. piano, violin,† mandolin,† guitar,† etc.

*The pitch of the note produced by a vibrating string depends upon three factors*--(i) *the length of the string*, (ii) *the tension of the string*, and (iii) *the weight per unit length of the string.*

We can show the effect of these three factors experimentally, using a *sonometer*, as shown in Fig. 111.

## TO SHOW HOW PITCH DEPENDS ON LENGTH OF STRING

Fasten a piece of thin wire A to both ends of a *sonometer* as shown in Fig. 111. Fasten a second piece of the same wire B to the top end of the sonometer and hang a weight of 4 lb. from the bottom end. Adjust the tension of wire A until it gives the same note as B. By means of a movable 'bridge' shorten the length of the vibrating part of B. Notice that the *pitch* of the note is raised. Make the vibrating part of B *half as long* as the vibrating part of A. The note produced by B is called the *octave*† of the note produced by A. Hence, with the same string at the same tension, *the pitch of the note produced depends on the length of the string*; the shorter the string the higher is the note produced, and vice versa.

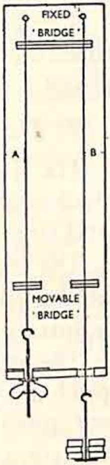


FIG. 111. Sonometer.

## TO SHOW HOW PITCH DEPENDS ON TENSION OF STRING

Hang a 2-lb. weight from the end of B and adjust the tension of A until both wires give the same note. Then hang a weight of 8 lb. from B so that the tension becomes four times as great. Notice that the note given by B is now *one octave higher* than that produced by A, i.e. the rate of vibration, or the frequency, has been *doubled*. Hence *the greater the tension of the string, the higher the note* (using the same length of the same string). (Actually, as your experiment suggests, the frequency of the note is proportional to the square root† of the tension.)

## TO SHOW HOW PITCH DEPENDS ON MASS OF STRING

Fasten two wires, one thicker than the other, to the top end of a sonometer, and hang a 4-lb. weight from the bottom end of each wire, so that their lengths and tensions are the same. Notice that *the heavier and thicker wire gives the lower note.*

## STRINGED MUSICAL INSTRUMENTS

Stringed musical instruments illustrate the application of all three factors governing the pitch of notes produced by a stretched string.

### (i) *The Violin*

The violin (see Fig. 115) has four strings made of gut* of different thicknesses. The strings are mounted on a hollow sounding-box and stretch from the tuning-pegs* across a wooden 'bridge'.

The thickest string gives the note of lowest pitch. The strings are tuned to the proper pitch by turning the tuning-pegs and thus adjusting the tension.

The string is vibrated by means of a *bow*, and notes of different pitch are produced by pressing a finger-tip on the strings at different positions on the finger-board, thus altering the length of the vibrating string. These vibrating strings would produce only weak sounds if they were not mounted* on a hollow sounding-board (the 'body' of the violin) which also vibrates with the same frequency and thus increases the loudness of the sound by resonance.

The rich quality of violin music is determined by the specially selected* wood and special shape of the sounding-box and by the method of using the bow. The viola,† violoncello,† and double-bass† are other stringed instruments played with a bow. The guitar (6 strings) and mandolin† (4 pairs of strings) have a similar construction, but the sounds are produced by plucking* the strings and not by 'bowing'.

### (ii) *The Piano*

The notes of a piano are produced by the vibration of steel wires tightly stretched across an iron frame. These wires are of different length, thickness, and tension,* and their natural frequencies of vibration range from 27 to 4,096 cycles per second. There are just over seven 'octaves', each of twelve notes. Between the first notes of each succeeding octave there is a doubling of the frequency. In the modern piano there is a steady* increase of about 6 per cent. in the frequency as one passes up the musical scale from one note to the next.

The wires press upon a bridge (as in the violin) and this in turn presses on the flat wooden *sounding-board.* When one of the piano-keys is pressed down, a small, wooden, cloth-covered hammer is moved so as to strike a wire, thus producing the desired note. For most notes there are actually three wires of the same kind. The wires are normally prevented from vibrating by a 'damper',* which is lifted at the same moment as the key is pressed. If desired, all the dampers may be lifted at once by pressing the 'loud' pedal.* This allows a wire to go on vibrating after the key returns to its normal position. It also allows other wires in the piano to vibrate in resonance with the wire that is struck, thus enriching* the *quality* of the sounds. The mechanism that works the hammers is a very complicated system of levers; it lifts the damper, it removes the hammer from the wire as soon as it has struck, and it allows the striking action to be repeated very rapidly.

### WIND-INSTRUMENTS

All wind-instruments are resonance tubes with some means of setting the *column of air in vibration.* The simplest wind-instrument is the organ pipe. Take an open organ pipe similar to that shown in Fig. 113. Cut a rectangular piece of thin paper, a little smaller than the cross-section of the pipe, and hang it near the top of the pipe by means of cotton and wax (as in Fig. 112). Lower the paper into the pipe.

Blow air through the organ pipe and notice that the paper becomes violently shaken because the column of air inside the pipe is vibrating.

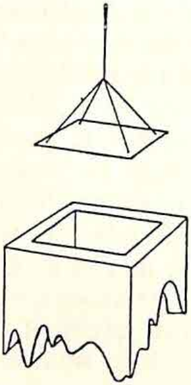


FIG. 112. Experiment with vibrating air column.

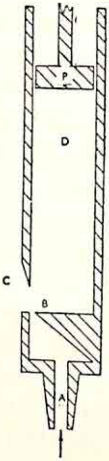


FIG. 113. Organ pipe without reed and closed by sliding piston P.

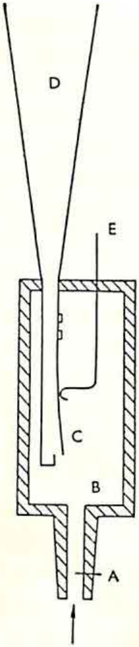


FIG. 114. Organ pipe with reed.
D = organ pipe. C = reed.
E = tuning wire. Air enters B through tube A.

## TO SHOW THE RELATION BETWEEN THE PITCH OF A NOTE AND THE LENGTH OF THE VIBRATING AIR-COLUMN THAT PRODUCES IT

(i) Blow gently into an organ pipe (Fig. 113). Slide a wooden piston P into the organ pipe D to shorten the length of its air-column. Is the pitch of the note higher or lower?

(ii) Place your finger-tips on all the holes of a 'tin whistle' or 'recorder'† and blow into the mouthpiece. Take your fingers off the holes one at a time so that the length of the air-column is decreased. The pitch of the notes is raised as the length of the vibrating air-column is shortened.

ORGAN PIPES. In an organ pipe, the column of air has its own natural frequency, and if vibrations of this frequency are produced near the air column it vibrates by resonance. In some organ pipes, vibrations of the right frequency are produced by forcing a jet of air against a thin strip of metal called the *reed*,† causing it to vibrate (see Fig. 114). The vibrations of the reed set the air in the organ pipe vibrating at the same frequency, and the corresponding musical note is produced. A simpler type of organ pipe has no reed, but air escapes from a narrow slit* (B) and strikes the sharp edge (C) of the opening at the bottom of the pipe (see Fig. 113). This sharp edge breaks up the jet of air into a series of puffs. One puff of air passes inside the pipe and the next passes outside, alternately, thus forming a series of alternate compressions and rarefactions inside the pipe with a definite frequency and so producing a musical note. Pipe organs are provided with a different pipe for every note: short pipes for the higher notes and long ones (sometimes 30 ft. long) for the lower notes.

WOOD-WIND INSTRUMENTS. The *flute* consists of a tube closed at one end. The performer blows a flat jet of air across a hole near the closed end and sets up vibrations that produce a musical note in much the same way as in a simple organ pipe. By uncovering holes along the instrument, the length of the vibrating air-column is varied and notes of different pitch are produced. In the *oboe*,† *clarinet*,† *saxophone*,† and *bassoon*,† the air-column is set in vibration by forcing air against a *reed* at the upper end of the instrument. The length of the vibrating air-column (and hence the pitch of the note produced) is varied by uncovering holes along the sides of the instrument.

BRASS INSTRUMENTS. In brass wind-instruments, the lips of the performer serve as a reed and the frequency of the vibrations is controlled by varying the air pressure and also the tension of the lips. The *bugle*† has no means of varying the length of the air-column; hence it can only produce a few notes whose frequencies bear a simple relation to one another. Instruments such as the *cornet*† and *trumpet*† are fitted with valves that vary the length of the air-column. In the *trombone*,† the length of the vibrating air-

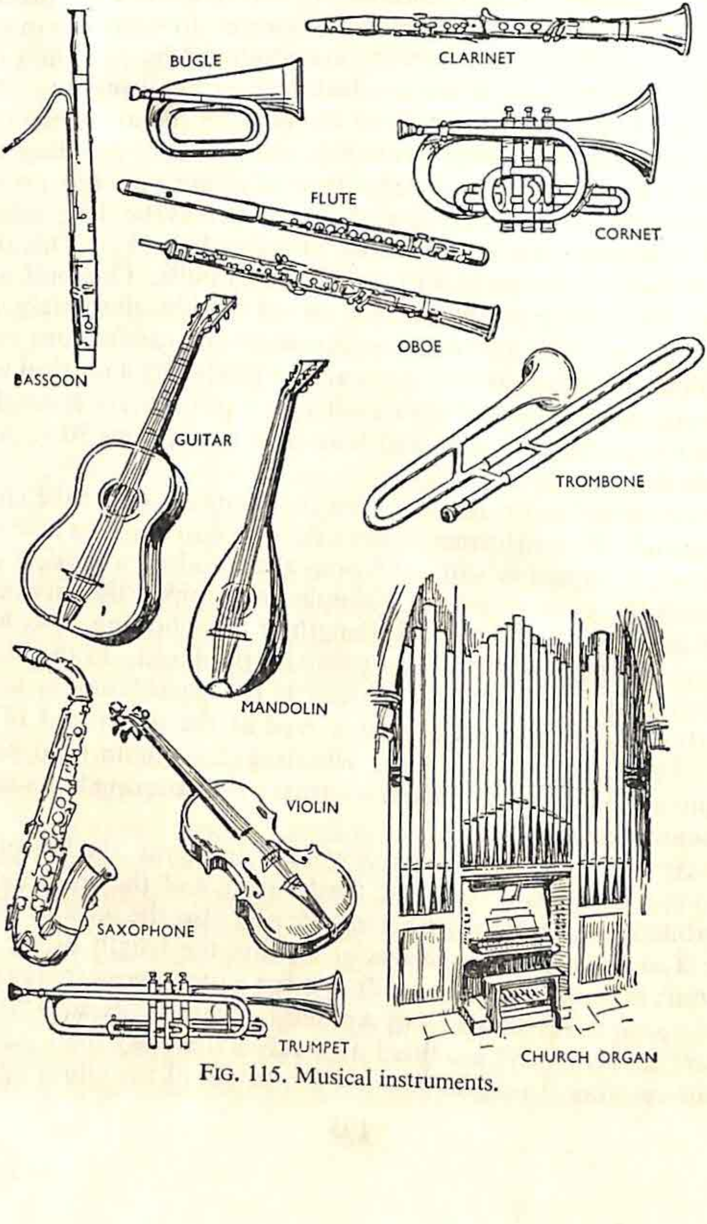


FIG. 115. Musical instruments.

column is varied by sliding a 'U'-shaped tube in and out, thus shortening or lengthening the air-column.

### THE GRAMOPHONE

In the original gramophone invented by Edison in 1877, the sound-waves were directed by a hollow cone† (A) on to a thin sheet of metal (B) that vibrated 'in step' with the sound-waves (see Fig. 116). There was a sharp point attached to the middle of this thin metal sheet, by means of which its vibrations were recorded on a revolving cylinder covered with soft wax. The shape and depth of the groove cut in the wax corresponded to the vibrations of the sound. When this '*record*' was played back with the same apparatus, the sharp point followed the wavy groove, reproducing the original vibrations of the thin metal sheet and thus setting up in the surrounding air waves of compression and rarefaction like those of the original sound-wave.

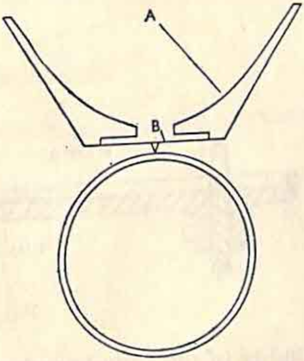


FIG. 116. Early gramophone. A = cone or horn. B = Thin metal sheet with sharp needle point in centre.

Nowadays, records are made on flat discs by electrical methods, and the needle vibrates *from side to side* and not up and down as in the original type. An ordinary *sound-box* now consists of a needle connected to the middle of a thin sheet of *mica* (see Fig. 117). As the record revolves, the needle vibrates according to the shape of the groove in the record, and the sound is reproduced by the vibrations of the mica, which set up corresponding sound-waves in the air. If a gramophone is to reproduce sounds at the *same pitch* as the original, the record must revolve at the *same speed* as when the record was made.

THE HUMAN VOICE. The human voice is produced by a wind instrument—the *voice-box* or *larynx*.† The two *voice-cords** (or vocal-cords†), which stretch across the *voice-box* at the top of the windpipe, behave like the reed in an organ pipe. When air is forced between the voice-cords from the lungs, they vibrate and produce a sound. The pitch of this sound is varied by muscles that alter the tension and length of the voice-cords. The loudness and quality of the sound produced also depend on the resonance of the air in the throat, mouth, and nose.

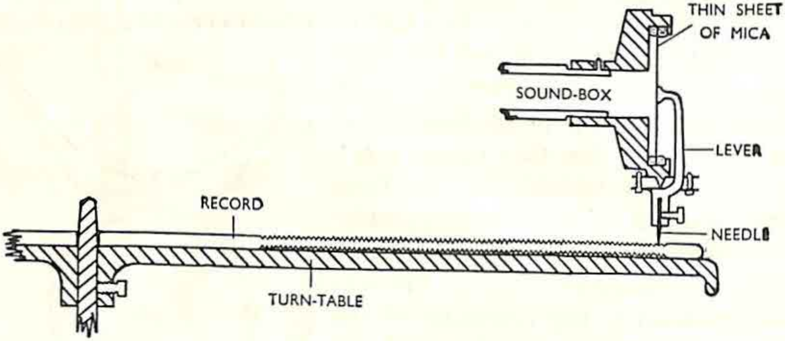


FIG. 117. Gramophone.

We shall discuss the structure of the voice-box (and of the human ear) later in this General Science Course, when you know more about the way your body works.

Learning Exercises on Chapter VII will be found on pp. 57–63 of *General Science Workbook I.*

*Note*.—The student should not part with this book. In studying Books III–IV he may want to refer back to the Glossary and to the Technical Terms marked with a dagger sign (†) in the Index.

# GLOSSARY

(Simple definitions of general-purpose words in the text that are not included in the standard vocabulary on which the Course is based and which were not used in Book I.)

*accumulate*, collect together, heap up, form a heap, 163
*adapt*, make fit or suitable, 63
*algebra*, branch of mathematics in which letters and signs are used to represent numbers, 77
*alternate*, first one and then the other, 151
*apart*, not together, 182
*ascent*, act of going up, 71
*assimilate*, absorb, 109
*attach*, fasten, cause to stick, 11
*automatic*, working of itself, self-acting, 82

*botanist*, student of botany (the science of plants), 53
*brake* (*n.*), apparatus for checking movement of train, etc., 82
*breed*, produce or raise young ones, 173
*bulb*, (here) roundish swelling at end of glass tube, 16

*canvas*, strong, coarse cloth used for sails, bags, tents, etc., 123
*cavity*, hollow within a solid body, 66
*char*, blacken as with fire, 35
*cinema*, hall where moving pictures (films) are shown, 186
*civil*, (here) concerning citizens, 77
*click*, slight sharp sound, 64
*composite*, made up of different parts, 143
*concave*, curving inwards like the inside of a ball or circle (opp. *convex*), 57
*confirm*, make more certain, 24
*constant*, not varying, 77
*contact*, state of touching, 5
*contour*, line on map showing points at same height above sea-level, 162
*contrary*, opposite, 160
*conversely*, in the opposite sense, 76
*convert*, change (into), 139
*convex*, with the surface curved like the outside of a ball (opp. *concave*), 58

*cord*, thick string, cord-like part of body, 197
*corrosive*, producing *corrosion* (the eating away of a substance from the surface by chemical action), 35
*crane*, machine for raising and moving heavy weights, 94
*crumbs*, particles of bread; particles like bread-crumbs, 8
*crust*, hard surface or covering, 150
*cube*, solid with six square sides, 23

*damper*, (here) pad of cloth to quieten sound, 193
*dawn*, first light of day, 112
*diffusion*, spreading (gas, smell, etc.) around, 50
*digest*, change food in the body so that it can be absorbed, 148
*disperse*, cause to go in different directions, 145
*drip*, fall, or let fall, in drops, 18
*drought*, continuous dry weather causing distress, 125

*eject*, force (steam, liquid, etc.) out of a place, 89
*elementary*, early, not advanced, 67
*emergency*, sudden action which makes quick action necessary, 187
*enormous*, very large, 94
*enrich*, make rich, improve, 193
*evidence*, facts which can be used to prove, 151
*exert*, bring into use, 61
*exhaust*, use up the whole of, empty, 169
*expenditure*, money spent, 123

*factor*, one of the causes of a result, 71
*fizz*, rapid formation of bubbles with *hissing* sound, 8
*foam*, (form a) collection of small bubbles, as on sea waves, 16
*forecast* (*n.* and *v.*), estimate (of) future thing, especially weather, 70
*fountain*, jet of liquid, 26
*friction*, rubbing of a thing against another, 72
*fume*, (form a) cloud of solid particles or liquid droplets, 24
*function*, special activity or purpose, 133
*furnace*, apparatus for creating great heat, 10

*gelatine*, clear, tasteless substance, made by boiling bones and waste parts of animals, dissolved in water to make jelly, 157
*glaze*, give shiny *transparent* surface to, 23
*graze*, eat growing grass, 176
*groove*, hollow channel in the surface of anything, 126
*gut*, intestines, 192

*hack-saw*, tool for cutting metal, 178
*hiss*, sharp 's' sound, 5
*hoe*, garden tool for cutting weeds and loosening the surface of the soil, 162
*hydraulic*, worked by water-power, 93

*identify*, recognize or prove as being a certain person or thing, 2
*incline*, slope, 10
*income*, money received during a given length of time for one's work, receipts of trade, etc., 123
*individual*, single, 49
*interior*, in the inside, 113
*intermediate*, coming between, 160
*internal*, of or in the inside, 120
*inversely*, as between quantities one of which increases as the other decreases, 76
*irrigate*, supply (land, crops) with water (by means of water channels, etc.), *irrigation*, 161

*jerky*, with sudden stops and starts, 156
*jigsaw puzzle*, picture, etc., pasted on thin board and cut in irregularly shaped pieces which are to be fitted together again, 114

*knob*, rounded lump on surface or at end of thing, 135

*lather*, (make) *foam* as of soap and water, 15
*lever*, bar at one end of which force is produced (e.g. to move something) by a turning movement exerted at the other end around a fixed support (*pivot*)
*liberate*, set free, 131
*lick*, pass tongue over; *salt-lick* (*n.*), place where animals collect to lick salty earth, 23
*linen*, light cloth made of flax, from which shirts, sheets, etc., are often made, 32

*magnify*, make appear larger than the real size, 49
*maintain*, keep up, 86
*major*, greater or more important, 167
*mechanic*, one who makes or works machinery, 74
*mechanism*, working part of machine, etc., 113
*mount*, put and fix in position, 192
*mouse*, small, rat-like animal, 17
*muscle*, contracting part of arm, leg, etc., that moves it, 66

*oblong*, flat figure of this shape ▭, 173
*offspring*, children, 146
*oven*, enclosed place for baking, 154

*partner*, person, etc., who takes part with another or others in the work and proceeds of some activity, 170
*pasture*, grass on land where cattle graze, 174
*pedal*, part of a machine or instrument worked by the foot, 193
*peg*, stout wooden or metal pin, 192
*pen* (*cattle-*), small enclosure for cattle, 171
*percentage*, number of units in every hundred units, 10
*permanent*, lasting, 17
*pit*, hole in the ground, 173
*pluck*, pull, 192
*plug*, stop up, 159
*pneumatic*, filled with, working by means of, compressed air, 73
*previous*, that come (came) before, 14
*prickle*, sharp point on stem or leaf, 126
*primitive*, of an early or undeveloped kind, 175
*product*, result of multiplying quantities together, 77
*puff*, short, sudden rush of air, 182
*pungent*, sharp, stinging, 24

*railing*, metal bars or tubes placed end to end as horizontal part of fence, 181
*rebound*, spring back, 50
*release*, set free, allow to go, 50
*represent*, stand for, 164
*reservoir*, vessel or space containing reserve supply of water, 81
*restrict*, kept within limits, limited, 52
*retain*, keep in place, not let go, 159
*revolution*, single complete turn (of wheel, etc.), 179
*ribs*, bones that form the chest, 66
*ridge*, narrow raised strip (of ground, etc.), 161
*rocket*, firework that explodes high in the air and falls in sparks, 182

*seal*, (here) close tightly, e.g. so as to keep air or water from passing, 64
*sediment*, matter that settles to bottom of liquid, 152
*sensation*, consciousness of something affecting the body or its parts, 186
*sensitive to*, easily affected by, 125
*sheath*, close-fitting cover for a sword or anything of similar shape, 145
*skis*, long strips of wood strapped to the boots for moving over snow, 59
*slit*, long cut or opening; also (*v.*), make a slit, 195

*sole*, (here) the under part of the foot, boot, etc., 59
*sounding*, test of the depth of water, 186
*spray*, apparatus for throwing a spray, i.e. liquid flying in fine drops; also *v.*, 88
*squirt* (*n.* and *v.*), *syringe*, 82
*stroke*, one of the regular movements of a machine; a blow, 86
*submerge*, cover with water, 57
*suction*, sucking, 65
*sufficient*, enough, 51
*suggest*, cause (idea) to present itself, 48
*surveyor*, one who determines the limits, size, shape, etc. (of country lands), 68
*swamp*, soft, wet land, 159
*syringe*, apparatus for throwing a fine stream of liquid; also *v.*, 61

*temporary*, not lasting, opposite of permanent, 17
*tension*, state of, degree of, being tightly stretched, 192
*terrace*, level shelf of land made on hillside for cultivation, 162
*theory*, rules and principles as distinguished from practice, 49
*transfer*, carry from one position or container to another, 90
*transform*, change something into something else, 111
*transmit*, send across, pass on, 91
*transparent*, that can be clearly seen through, 23
*tunnel*, make an underground passage, 159
*tyre*, band, tube, cover of rubber, etc., placed round wheel, 72

*ventilate*, cause air to move in and out freely, 159
*vice versa*, the other way round, 50
*victim*, person or animal killed or hurt as the result of cruelty, accident, etc., 23

*wedge*, sharp-edged piece of metal, etc., as used for splitting wood, 58
*wick*, porous strip or thread feeding flame of lamp with oil, 59
*wilt*, droop from lack of water, lose freshness, 122
*wither* (of plants), become dry and lose life after *wilting*, 133

# INDEX

WHERE there are several page-references to the same subject, the main reference is printed in heavier type. The dagger-sign (†) in front of a word shows that this is a technical word that was not used in Book I, and which is not explained in the Glossary. These new technical words are also marked (†) where they first appear in the text, and where their meaning is explained.

acidic oxides, 34.
acids, 33–40.
†adhesion, 56–57.
†adsorption, 156–7.
†Agave, 126.
air in soil, 157–9.
— pressure, 60–91.
alkalis, 40–43.
†Allamanda, 128.
†alluvial deposits, 152.
†altimeters, 68.
†altitude and pressure, 71.
†aluminium oxide, 151.
†— silicate, 156.
†ammonium chloride, 26–27.
†— hydroxide, 42–43.
— sulphate, 37, **171**.
†aneroid barometer, 68–70.
animal manure, **170**, 174.
†Annatto, **130**, 147.
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